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Superheated-Steam Test of Ethylene Propylene Rubber Cables Using a Simultaneous Aging and Accident Environment

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ABSTRACT

The superheated-steam test exposed different ethylene propylene rubber (EPR) cables and insulation specimens to simultaneous aging and a 21-day simultaneous accident environment. In addition, some insulation specimens were exposed to five different aging conditions prior to the 21-day simultaneous accident simulation. The purpose of this superheated-steam test (a follow-on to the saturated-steam tests (NUREG/CR-3538)) was to (1) examine electrical degradation of different configurations of EPR cables, (2) investigate differences between using superheated-steam or saturated-steam at the start of an accident simulation, (3) determine whether the aging technique used in the saturated-steam test induced artificial degradation, and (4) identify the constituents in EPR that affect moisture absorption.

The cable electrical degradation was determined by insulation resistance and AC leakage current measurements. One aged multiconductor cable product had electrical degradation, although the aged single conductor cable did not have electrical degradation. Therefore, the current qualification practice of using single conductor cables to qualify multiconductor cables may not be a conservative approach for all cables. Physical and tensile properties (measured after the accident) for insulation specimens did not improve as the accelerated aging time was increased. Therefore, the aging technique did not induce artificial degradation. In addition, the constituents that appear to affect moisture absorption and/or produce other chemical changes are fire retardants, nonsurface treated clay, or lack of vinyl silane.

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EXECUTIVE SUMMARY

The purpose of the superheated-steam test (a follow-on test to the saturated-steam tests discussed in NUREG/CR-3538) was to:

1. Examine electrical degradation of single conductor, multiplex, and multiconductor ethylene propylene rubber (EPR) cables,

2. Investigate the effect of using superheated-steam rather than saturated-steam at the start of an accident simulation,

3. Determine whether or not the aging technique, used during the aging portion of the saturated-steam test, influenced moisture absorption in the insulation and thereby induced artificial degradation, and

4. Identify the constituents in EPR which affect moisture absorption and dimensional swelling.

To answer these questions, three subtests were conducted. In Subtest 1, three cable types (EPR D lot 1, EPR D lot 2, and EPR H) were exposed to simultaneous aging and a 21-day simultaneous accident environment. These cables were in three different configurations: single conductor, multiplex, and multiconductor. In Subtest 2, EPR D lot 1 and EPR F insulation specimens were exposed to five different aging conditions and then to the 21-day simultaneous accident environment. In Subtest 3, EPR-1483 insulation specimens and five variations of EPR-1483 were exposed to simultaneous aging and the 21-day simultaneous accident environment. The constituents of EPR-1483 that were varied included fire retardant, surface-treated clay, and vinyl silane.

The results of Subtest 1 have shown that aged EPR D lot 1 multiconductor cables (but not the aged single conductor, aged multiplex, or unaged multiconductor cables) experienced substantial electrical degradation when superheated-steam conditions were used at the start of the LOCA profile. Electrical degradation (the cables failed to maintain high insulation resistance values) occurred between 19 and 21 days into the accident simulation--slightly later than in the saturated-steam test. Furthermore, for these aged multiconductor cables, the jackets were split at the conclusion of the accident simulation and the cables failed

the one minute at 1800 Vac test (which is less severe than the five minute 80 V/mil withstand test.) EPR D lot 2 and EPR H did not show different electrical results between single and multiconductor configurations. These cables even passed the five minute 80 V/mil withstand test.

The results of Subtest 2 showed that the physical and tensile properties (measured after the accident simulation) did not improve as the accelerated aging time was increased.

Although all EPR-1483 insulation specimens in Subtest 3 showed a chemical change after the accident simulation, removing the surface treatment of the clay or the vinyl silane bonding caused a loss of ingredients and other chemical changes. In addition, insulation specimens without a fire retardant absorbed less moisture and had better tensile properties than those with either a chlorine or bromine fire retardant.

From the results of the three subtests and the saturated-steam test, the following conclusions were drawn:

1. Since only one product (aged multiconductor EPR D lot 1 cable) had low IR values and large leakage currents, the differences between the electrical degradation of single and multiconductor cables do not appear to be generic to all cables. However, because single conductors and multiconductors did behave differently for the aged EPR D lot 1 cables, the current equipment qualification practice of using single conductors to qualify multiconductors may not be a conservative approach for all cables.

2. Since cable electrical degradation was not observed until several days after the start of the accident exposure, safety systems that are required only at the start of an accident may not be impacted by this degradation process.

3. Since the same results occurred using either superheated-steam or saturated-steam at the start of the accident simulation, it does not appear that saturated-steam conditions forced moisture into the cable causing the cable to fail prematurely. (Superheated-steam only delayed the electrical degradation of the cables slightly.)

4. It was suggested, in the saturated-steam test, that the single conductor showed no electrical degradation due to the absence of jacket-insulation interaction effects and less severe bending (no helical bend component). Because the multiplex cable,in the superheated-steam test, had no

electrical degradation, the primary cause of multiconductor failure is due to the jacket-insulation interaction effects.

5. EPR D lot 1 was certified to LOCA requirements, but failed to maintain high insulation resistance values throughout the test. EPR D lot 2, although not certified, passed the test. From a chlorine and bromine analysis, the insulation was found to be different for each lot. However, since the physical and tensile properties were similar between batches of EPR-1483 (from Subtest 3) with a chlorine or a bromine fire retardant, other formulation differences and the processing between lots 1 and 2 may also be different.

6. The aging dose rates and temperatures in the superheated-steam and saturated-steam tests were not inducing artificial degradation because the physical and tensile properties (measured after the accident simulation) did not improve as the accelerated aging time was increased.

7. The constituents that appear to affect moisture absorption and/or produce other chemical changes are fire retardants (chlorine or bromine), nonsurface treated clay, and lack of vinyl silane.

1. INTRODUCTION

The report, "The Effect of LOCA Simulation Procedures On Ethylene Propylene Rubber's Mechanical and Electrical Properties (NUREG/CR-3538)," included two tests with simultaneous thermal and radiation aging and a simultaneous radiation and steam accident environment (Reference 1). The temperatures for the accident profiles were similar to those of the LOCA profile of IEEE 323-1974. The pressure profile was based on saturated-steam conditions associated with those temperatures. These tests will hereafter be referred to as the saturated-steam tests.

One aged, ethylene propylene rubber (EPR) cable product in the saturated-steam tests showed the following result: the multiconductor cable had substantial electrical degradation but no electrical degradation was apparent for the single conductor cable. This aged, EPR D lot 1 multiconductor cable also had moisture absorption and swelling. It was hypothesized that the dimensional swelling of the insulation caused stress buildup within the multiconductor geometry. When the jacket split to relieve the stress, the sudden release of constrictive force on the insulators may have caused cracking or breakup of the insulation. It was suggested that EPR D lot 1, single conductor cable performed better due to the absence of jacket-insulation interaction effects and less severe bending (no helical bending).

In the past, the jacket was considered to provide protection to the multiconductor cable that was not available to single conductor cables. Because of this, IEEE 383-1974 allowed qualification tests for single conductor cables to be used as a basis for qualification of multiconductor cables. However, the results of the saturated-steam tests indicate that this may not be the most conservative approach for all cables.

Because this conclusion could impact current equipment qualification regulations, the test conditions were re-examined. A question was raised as to whether using saturated-steam conditions, rather than superheated-steam conditions, at the start of the accident profile may have forced moisture into the cable and have caused the cables to fail prematurely.

In order to address this question and several other questions arising from the saturated-steam cable tests, a superheated-steam test program was conducted. The questions to be answered include:

1. Will EPR D lot 1 multiconductor cables experience substantial electrical degradation if superheated-steam rather than saturated-steam conditions are used at the start of the LOCA profile?

2. Do other EPR cable products show different electrical results between single and multiconductor configurations?

3. Does the aging technique influence moisture absorption in the insulation?, and

4. What constituents of the insulation influence moisture absorption?

The radiation, temperature, and pressure levels of the superheated-steam test were similar to those of the previous saturated-steam test. For aging, a slightly lower dose rate was used. For the simultaneous accident exposure, the differences included using superheated-steam conditions at temperatures above 154°C and lower dose rates.

The superheated-steam test was composed of the three subtests described below.

<u>Subtest 1</u>

The purpose of this subtest was to answer two questions: (1) Will EPR D lot 1 multiconductor cables experience substantial electrical degradation if superheated-steam rather than saturated-steam conditions are used at the start of the LOCA profile? and (2) Do other EPR cable products show different electrical results between single and multiconductor configurations? In addition, this subtest provided a comparison between different cable lots and information on jacket-insulation interaction by including three configurations of cables.

Subtest 1 included three EPR cable products: EPR D lot 1, EPR D lot 2, and EPR H. Three different configurations of cabling (multiconductor, multiplex, and single conductor) and insulation specimens were included. Multiplex, single conductor, and insulation specimens were created by disassembling multiconductor cables. Therefore, the manufacturing process was the same for all specimens.

The test specimens were subjected to simultaneous aging equivalent to forty years at 55°C: 40 Mrad (at 0.27 Mrad/hr for 149 hrs) and 139°C for 167 hours. Aged, as well as unaged test specimens, were subjected to the accident profile. The 21-day simultaneous accident profile included approximately 110 Mrad and a steam environment with a maximum temperature of 171°C and a maximum pressure of 448 kPa (65 psig).

Subtest 2

The purpose of Subtest 2 was to determine if the aging technique, used during the aging portion of the saturated-steam test, influenced moisture absorption in the insulation and thereby induced artificial degradation. If moisture absorption remains constant, even though the aging time is increased, then the increase in moisture would appear to be realistic--not an artifact of the accelerated aging technique. However, if differences in moisture absorption are found by using different dose rates and aging temperatures, then the aging technique used in the previous, saturated-steam experiment may have produced artificial degradation.

EPR D lot 1 and EPR F insulation specimens were prepared from multiconductor cable and single conductor cable, respectively. These insulation specimens were exposed to five different simultaneous thermal and radiation aging conditions using progressively lower temperatures (155°C to 103°C) and lower dose rates (765 krad/hr to 16 krad/hr). The specimens were exposed to the same equivalent age: (1) 50 Mrad and 40 years at 55°C or (2) 25 Mrad and 20 years at 55°C (assuming a 1.04 eV activation energy). These samples were then exposed to the accident simulation described in Subtest 1.

Subtest 3

The purpose of Subtest 3 was (1) to identify constituents which cause moisture absorption and dimensional swelling in the insulation and (2) to help establish the applicability of the test results to other cable products. This was done using a nonproprietary formulation (EPR-1483).

EPR insulation is comprised of approximately forty percent EPR polymer by weight. The remaining sixty percent of the formulation includes fire retardants, clay fillers, coupling agents, and other ingredients. The presence of these constituents may affect the moisture absorption of the insulation. For the superheated-steam test, the fire retardant, clay filler, and coupling agent were changed.

EPR 1483 and five variations of EPR 1483 were exposed to simultaneous thermal and radiation aging: 300 krad/hr and 141°C for 167 hours or 300 krad/hr and 141°C for 83.5 hours.

The specimens were exposed to the same equivalent age: (1) 50 Mrad and 40 years at 55°C or (2) 25 Mrad and 20 years at 55°C (assuming a 1.04 eV activation energy), respectively. These samples were then exposed to the accident simulation described in Subtest 1.

2. MATERIALS

The following commercial EPR products were used in this test:

1. EPR D lot 1: A three conductor, 600 V, control cable with flame-retardant EPR insulation. The jacket is made of chlorinated polyethylene. The cable met the requirements of IEEE 383-1974 and was purchased from the manufacturer by Sandia National Laboratories in 1981.

2. EPR D lot 2: The same cable product as lot 1; however, the manufacturer did not certify that it met IEEE 383-1974 requirements. The cable was purchased in 1984 from a distributor for the manufacturer.

3. EPR F: A single conductor, 600 V power and control cable with flame-retardant EPR insulation. The cable met the requirements of IEEE 383-1974 and was purchased from the manufacturer by Sandia National Laboratories in 1982.

4. EPR H: A three conductor, 600 V, power and control cable which is a multiconductor version of EPR F. The cable has a flame-retardant EPR insulation and a vulcanized chlorosulfonated polyethylene jacket. The cable met the requirements of IEEE 383-1974 and IEEE 323-1974 and was obtained from the Washington Public Power Supply System in 1985.

5. EPR 1483 and five variations: The nonproprietary formulation of EPR 1483 is similar to the commercial EPR products in use in nuclear power plants (Reference 2). The formulations for the six compounds are given in Table 1 and the differences between the six compounds are identified in Table 2. These six compounds were mixed, cured, and made into sheets by the Akron Rubber Development Laboratory, Inc. These sheets were purchased in 1984. (The data from Akron Rubber Development Laboratory is found in Appendix A).

These materials were used in the following forms:

1. Cables as received from the factory: multiconductor cable (EPR D lot 1, EPR D lot 2, and EPR H) and single conductor cable (EPR F).

2. Multiplex cable: Multiplex cables are multiconductor cables with the outer jacket removed. The conductors remain in their twisted (multiconductor) configuration (EPR D lot 1 and EPR H).

Table 1

Formulations of EPR 1483 and Five Variations

Amount (Parts/Hundred)

Batch:	1	2	3	4	5	6
Nordel 2722	90.0	90.0	90.0	90.0	90.0	90.0
DYNH No. 1	20.0	20.0	20.0	20.0	20.0	20.0
Zinc Oxide	5.0	5.0	5.0	5.0	5.0	5.0
Paraffin wax	5.0	5.0	5.0	5.0	5.0	5.0
Zetax	2.0	2.0	2.0	2.0	2.0	2.0
Aminox	1.0	1.0	1.0	1.0	1.0	1.0
Translink 37	60.0	60.0	60.0	-	-	60.0
Silane A-172	1.0	1.0	1.0	1.0	1.0	-
SRF N774	2.0	2.0	2.0	2.0	2.0	2.0
Litharge	5.0	5.0	5.0	5.0	5.0	5.0
DiCup R	5.0	5.0	5.0	5.0	5.0	5.0
Dechlorane +25	33.0	-	-	33.0	33.0	33.0
Antimony Trioxide	12.0	-	12.0	12.0	12.0	12.0
Burgess KE	-	-	-	60.0	-	-
Whitex	-	-	-	-	60.0	-
Saytex 102: (Br fire retardant)	-	-	33.0	-	-	-

Table 2

EPR 1483 and Five Variations

Batch #	
1	EPR 1483
2	EPR 1483 minus the fire retardant (Dechlorane plus 25 and Antimony Trioxide)
3	EPR 1483 minus the chlorine fire retardant (Dechlorane plus 25) plus a bromine fire retardant (Saytex 102)
4	EPR 1483 minus the surface treated, calcinated clay (Translink 37) plus a different surface treated, calcinated clay (Burgess KE)
5	EPR 1483 minus the surface treated, calcinated clay (Translink 37) plus a nonsurface treated, calcinated clay (Whitex)
6	EPR 1483 minus vinyl-silane coagent (Silane A-172)

3. Single conductor cable: The single conductors are multiplex cables with each conductor separated from the multiplex configuration (EPR D lot 1, EPR D lot 2, and EPR H).

4. Insulation specimens: Some insulation specimens were obtained by removing the jacket and sheath from the EPR insulated conductor, carefully stripping the insulation from the stranded copper conductor, and cutting the insulation into 10.9 cm lengths (EPR D lot 1, EPR D lot 2, EPR F, and EPR H). Other insulation specimens (EPR 1483) were cut from 15.2 cm x 15.2 cm x 0.2 cm sheets into strips with the following dimensions: 10.9 cm x 0.63 cm x 0.2 cm.

3. FACILITIES

3.1 LICA Facility

The Low Intensity Cobalt Array (LICA) radiation facility, at Sandia National Laboratories, was used for aging insulation specimens. This facility is shown in Figure 1. The LICA pool, in which approximately 16,000 curies of Co^{60} are submerged, is filled with recycled demineralized water. The depth of the pool is approximately 5.8 m to provide a radiation shield for experimenters.

3.1.1 Arrays

The LICA consists of three basic arrays: the North Linear Array, South Linear Array, and Circular Array. For our aging exposures, the South Linear Array and Circular Array were used. These arrays are discussed in the following paragraphs.

South Linear Array

The South Linear Array is shown in Figure 2. The array consists of six test cells holders, each containing four cylindrical holes, which are positioned parallel to two linear cobalt holders. Together, the two linear cobalt holders contain approximately 3000 curies of Co^{60}.

The radiation dose rate of any hole in a given test cell holder is comparable to the dose rate of the other three holes. The radiation dose rate for each position is given in Figure 2. (The dose rates are only valid provided blocking cans are used).

Circular Array

The Circular Array, shown in Figure 3, contains approximately 10,000 curies of Co^{60} and consists of three rows of three cylindrical holes. Since the cobalt surrounds the center hole, the highest dose rate in the Circular Array is found in the center hole. The dose rate for each hole is also given in Figure 3. (The dose rates are only valid provided blocking cans are used.)

3.1.2 Test Positions

The insulation specimens were aged in the following locations: (1) 1B, 1C, 2C, 3B, 3C and 5D, of the South Linear Array, and (2) 1Y, 2X, 2Y, 2Z and 3Y of the Circular Array.

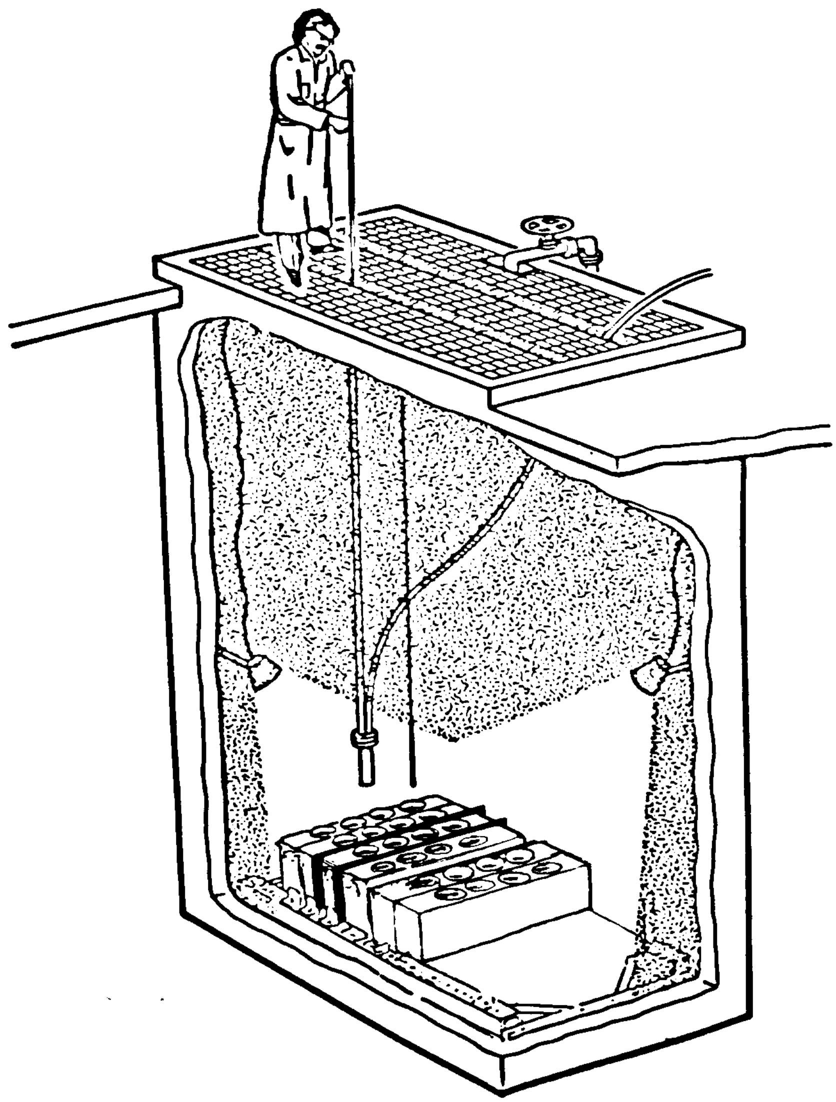


Figure 1. Artist's Rendition of the LICA Facility

13.6	15.5	15.5	13.6	1*
44.6	47.5	49.5	52.4	2*
COBALT HOLDER				
109	107	107	113	3*
A	B	C	D	
112	112	113	112	4*
COBALT HOLDER				
47.5	53.4	54.3	51.4	5*
15.5	18.4	17.5	14.6	6*

* 1-6 indicates test cell holders

Figure 2. South LICA Linear Array Dose Rates (krad/hr) for November 1, 1984

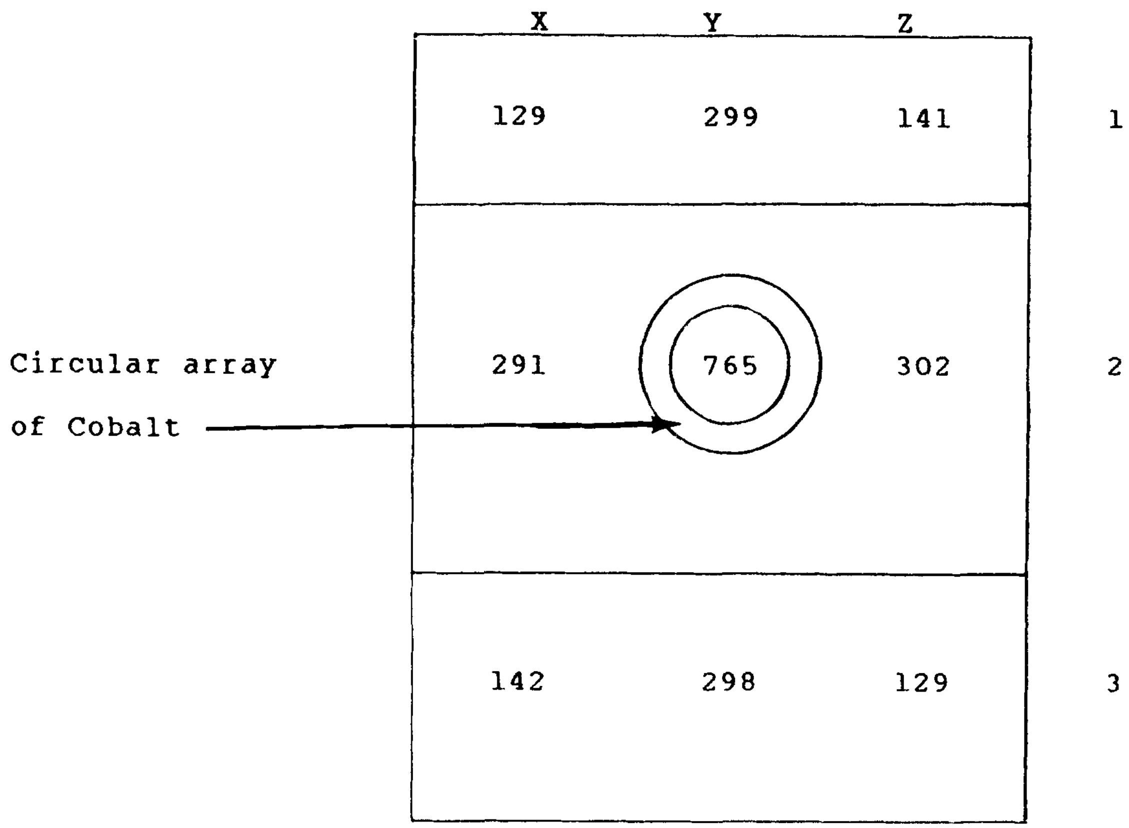


Figure 3. LICA Circular Array Dose Rates (krad/hr) for November 1, 1984

3.1.3 LICA Fixtures

A perforated LICA fixture, shown in Figure 4, was used to hold EPR D lot 1 or EPR F insulation samples within the test cavity without having the samples touch the inner wall of the test cell or each other, thus preventing melting and fusion of the samples. The LICA fixture consists of two circular plates of perforated stainless steel (with holes slightly larger in diameter than the insulation samples) and a bottom circular stainless steel plate. Each plate has a 1.3 cm (1/2 inch) semicircular notch on its edge. All the plates are assembled with the notches vertically parallel to each other so that the air flow tube of the test cell works

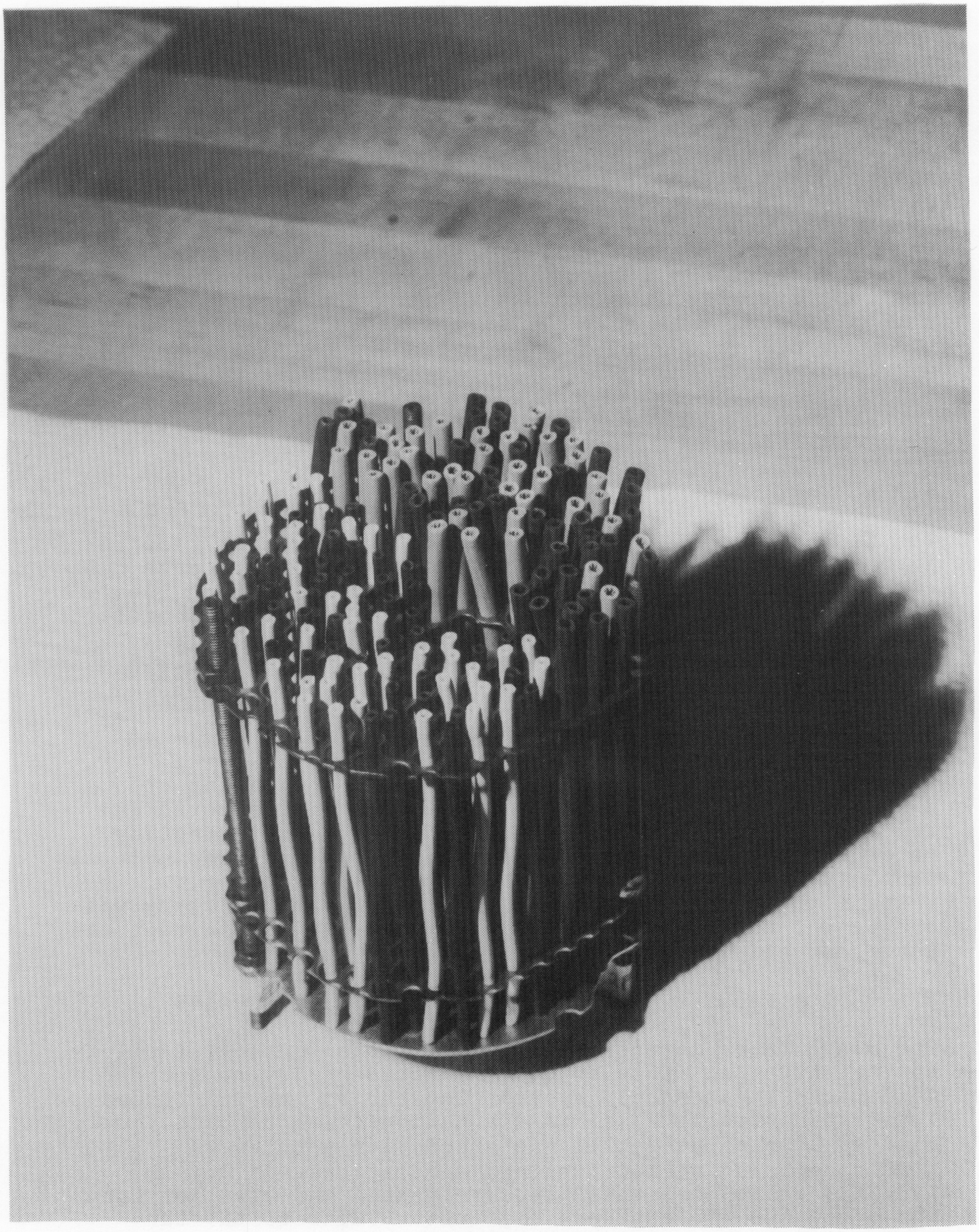


Figure 4. Insulation Specimens Held in LICA Fixture

as a guide for positioning the LICA fixture within the cell. The plates are held together with three stainless steel threaded rods to give a fixture height of 10.2 cm. The center plate can be adjusted to stabilize the samples in a vertical position.

The LICA fixtures for the EPR 1483 insulation samples were different from the above fixtures because the EPR 1483 strips did not fit in the small diameter holes. For the EPR 1483 fixtures, the perforated stainless steel was molded into a 12.7 cm tall cylinder shape with a stainless steel plate welded to one end of the cylinder. Stainless steel wire was run through the holes of the cylinder 2.5 cm and 5.1 cm below the top of the perforated stand to create six compartments. Each compartment in the fixture held three to five samples.

3.1.4 <u>Test Cans</u>

The LICA fixtures were sealed in the test cans and lowered into the proper space. See Figures 1 and 5. For each test can the airflow tube was positioned closest to the linear cobalt holder in the South Linear Array or to the center cobalt source in the Circular Array. This method of positioning allows for properly rotating the can to minimize the radiation gradient.

3.1.5 <u>LICA Aging of Samples</u>

At an aging exposure corresponding to an equivalent of 25 Mrad and 20 years, insulation samples were removed and the test can was rotated 180° in the clockwise direction. Before the test can was opened, the thermal control unit was shut off for five minutes and air was allowed to flow through the can to cool the LICA fixture. After aging was completed, the remaining insulation samples in the test can were removed.

3.2 HIACA Facility and LOCA/SAC Steam Supply System

The HIACA (High Intensity Adjustable Cobalt Array) facility and the LOCA/SAC (Loss of Coolant Accident/Severe Accident Condition) steam supply system, located at the GIF (Gamma Irradiation Facility) at Sandia National Laboratories, were used to expose the cables and insulation samples to simultaneous aging and accident simulations. A 0.45 m^3 (16 ft^3) stainless steel pressure vessel was used for both the aging and the accident exposure. (Henceforth, the stainless steel pressure vessel will be referred to as the test chamber.)

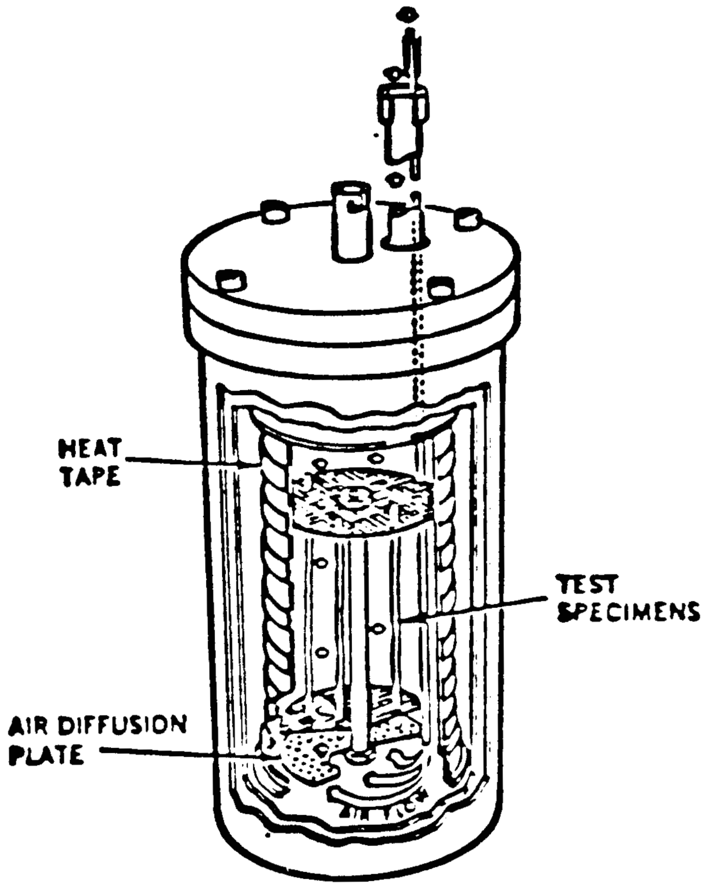


Figure 5. A LICA Irradiation Test Can

3.2.1 Operation for Simultaneous Aging Simulation

For the aging simulation, the test chamber is placed inside the GIF cell and connected to a recirculating hot air system. The hot air system consists of a 20kW circulation heater, a Chromalox 3CR temperature controller, a 2 hp Paxton blower and a piping configuration that provides for approximately 10 percent fresh air make-up to assure the presence of oxygen during aging. (A Kurz air velocity meter was used to check the flow conditions during set-up.) The chamber is equipped with a tubing system against the inside wall of the chamber which surrounds the test specimens. The 20 tubes exit the chamber into a manifold system that allowed the flow to each individual tube to be controlled. This method improved temperature uniformity by providing flow adjustment during the simulation without having to interrupt the thermal portion of the simulation. Once the experiment reaches the desired aging temperature and uniformity is achieved, the cobalt is raised to provide simultaneous aging conditions.

The 32 cobalt pencils are contained in the HIACA facility. The HIACA facility consists of an elevator system that positions the fixture approximately 25.4 cm under the pool level. Thirty-two telescoping tubes can then be raised hydraulically into the cell in 8 groups of 4 each. Figure 6 illustrates this capability. This capability is explained further in Reference 3. The aging dose rate (July 26, 1985) for 3, 4, 5, and 6 groups is given in Table 3.

3.2.2 Operation for the Two Transient, Simultaneous Accident Simulation

The LOCA/SAC simulator was used with the HIACA facility for the simultaneous accident sequence. Figure 7 shows the major components and piping of the LOCA/SAC simulator. The 6 hp boiler and immersion heaters charge the accumulators to operating pressure. Low pressure steam is then routed through the superheaters and is used to heat the Al_2O_3 balls in the regenerators to an average temperature of approximately 232°C. This process takes about 24 hours.

When the simulation is about to begin, the proper regulator is selected and the system is valved to direct flow through the regenerators to the test chamber. The test is then initiated by the opening of the air-actuated valve and the superheated steam enters the chamber. As the chamber reaches the desired pressure (in approximately 10-15 seconds), the superheat vent valve is used to control the amount of superheat (approximately 17°C). After the initial ramp is completed and the temperature has

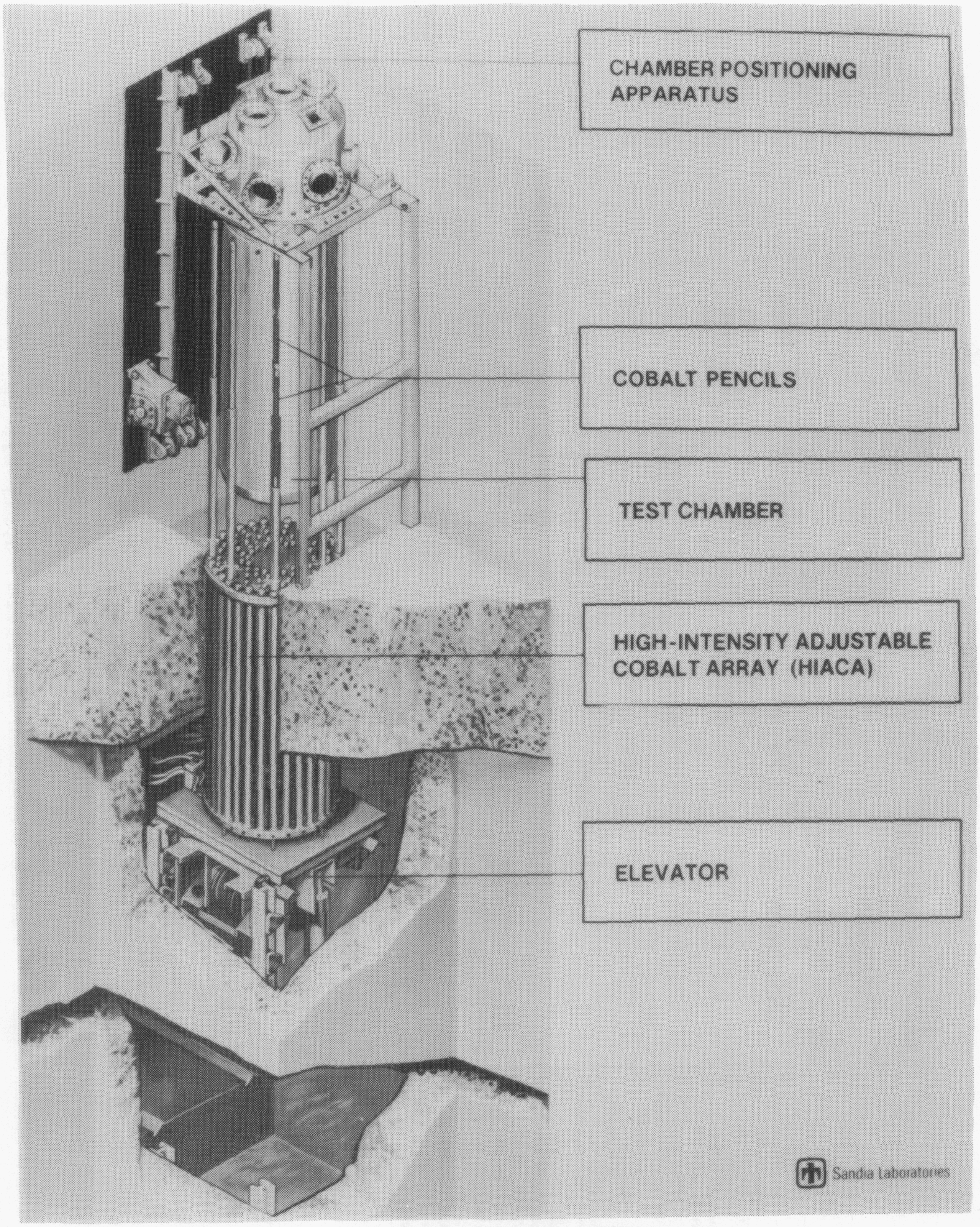


Figure 6. HIACA Test Facility

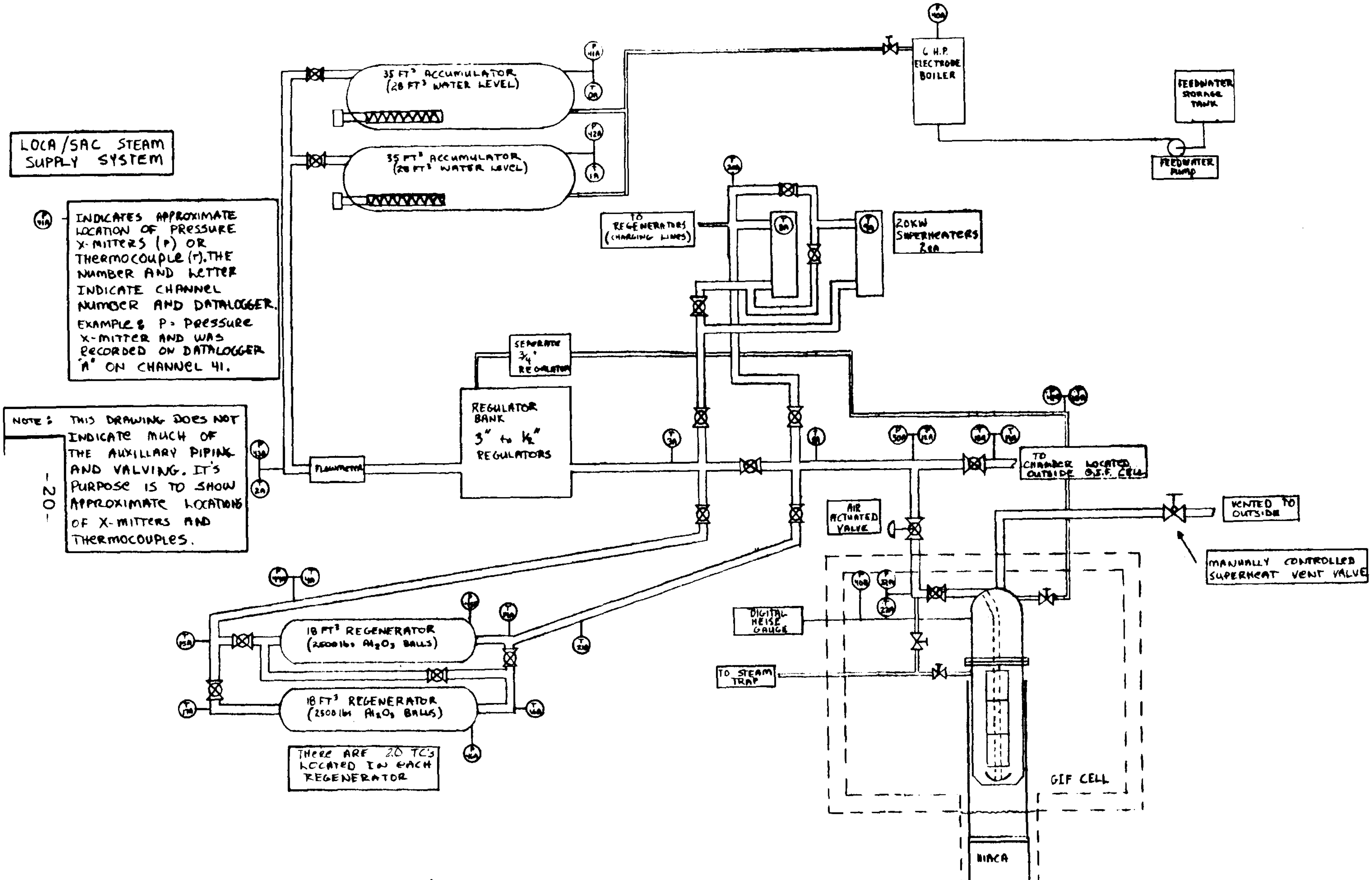


Figure 7. LOCA/SAC Steam Supply System

Table 3

Dose Rates Available for HIACA Aging July 26, 1985

Number of Groups*	Dose Rate (Mrad/hr)
1	
2	
3	.161
4	.215
5	.269
6	.323
7	
8	

* 4 pencils per group

Note: Radial uniformity achieved even with one group (Reference 3).

stabilized, the steam is routed directly through the superheaters. The regenerators are isolated, thereby conserving the stored heat for the second temperature and pressure ramp. The ramp-down portion of the test is accomplished using a separate regulator and line so the saturated steam does not cool down the main steam line. The procedure is then repeated for the second ramp. As for simultaneous aging, the cobalt was raised after each ramp when the chamber temperature had stabilized. The dose rate, calculated for August 26, 1985, for each group of pencils is shown in Table 4.

3.3 Other Test Considerations

3.3.1 Mandrels

Each cable specimen (total cable length approximately 23 m) was wrapped on a mandrel. Three mandrels were used for this test. Each mandrel is 38 cm high with an outside diameter of 30 cm. When the three mandrels are attached together, their total length is 114 cm with the edge of the top mandrel 31 cm below the chamber head sealing edge and the bottom of the mandrel stack approximately 11 cm above the bottom of the chamber.

Table 4

Dose Rates Available for HIACA Accident Simulation
August 26, 1985

# of Groups*	Dose Rate (Mrad/hr)
1	.048 ± 31%
2	.106 ± 19%
3	.160 ± 17%
4	.213 ± 14%
5	.266 ± 20%
6	.319 ± 19%
7	.372 ± 16%
8	.420 ± 16%

* 4 pencils per group

Note: Radial uniformity achieved even with one group (Reference 3).

The order of the cables on the mandrels is shown in Table 5. Each cable was wrapped three times around the mandrel with the center of the cable at the center wrap. After wrapping, the mandrel clips were wired in place to secure cable specimens in a fixed position. The third mandrel was wrapped separately and attached to the mandrel array after HIACA aging of the cable specimens on the first and second mandrels.

For the cables on Mandrels #1 and #2, the extra cable length was gathered in the center of the mandrels and fed through the flange pipe couplings. For cables on mandrel #3 (added to the steam chamber after the HIACA aging portion of the test), the extra cable lengths were positioned on the outside of the mandrels to minimize damage to the aged cable on mandrels #1 and #2. The cables on mandrel #3 were run through 50.8 cm (20-inch long) conduit elbows which were 2-inch in diameter prior to placement through the flange pipe couplings.

Table 5

Order of Cables, From Top to Bottom,
On Each Mandrel

Mandrel	Cables
1	EPR H: single conductor (red)
	EPR D lot 2: single conductor (white)
	EPR D lot 1: single conductor (black)
	EPR D lot 2: multiconductor
	EPR H: multiconductor
	EPR D lot 1: multiconductor
2	EPR D lot 1: multiplex
	EPR H: multiplex
	EPR D lot 2: multiconductor
	EPR H: multiconductor
	EPR D lot 1: multiconductor
3	EPR D lot 1: unaged
	EPR H: unaged
	EPR D lot 1: unaged
	EPR H: unaged

3.3.2 Flanges

As shown in Figure 8, the test chamber head had eight penetration sites with four of the sites reserved for the steam inlet, steam outlet, thermal aging unit, and thermocouple flanges. Since only four penetration sites remained and fifteen cable specimens (30 cable ends) were to be tested; a special cable penetration adapter was used on one of these penetration sites. All flanges and the penetration adapter were attached to the chamber head using 1/4-20 bolts which were torqued to 5.65 N-m (50 in-lb_f).

As shown in Figure 9, the cable penetration adapter was made to accommodate twelve cable end penetrations by welding 1-inch pipe couplings spirally along the outer edge of a 5-inch diameter stainless steel pipe (304 TS) with flange adapters on each end of the pipe. Four more cable end penetrations were made available on the end of the penetration adapter by attaching to it a flange with two 1-inch and two 3/4-inch pipe couplings welded to the flange. The cable penetration adapter was used at the penetration site for the eight multiconductor cables exposed to aging.

The three single conductor cables, to be exposed to aging, were run through another penetration site. As shown in Figure 10, a flange with five 1/4-inch and four 1/2-inch pipe couplings was attached to this penetration site. The extra three pipe couplings were plugged.

As shown in Figure 11, the last two penetration sites were fitted with flanges having two 1-inch and two 3/4-inch pipe coupling adapters each. These two flanges were used after thermal aging to accommodate the four, unaged multiconductor cables.

3.3.3 Potting Cables

The ends of the extra cable lengths were run through the various penetration sites and the pipe coupling adapters on the flanges. Thin-walled stainless steel tubing (20.3 cm long) with a Swagelok® male connector on one end and a Swagelok end-cap connector on the other end, was attached to each of the flange pipe couplings. The stainless steel tubing restricted the aging or accident environment to the interior of the test chamber.

The cable was sealed inside the stainless steel tube with epoxy. The epoxy was 3M Scotchcast No. 9. This epoxy has been tested and can withstand temperatures of 371°C at 1.2 MPa (180 psi). A hole, approximately 0.16 cm

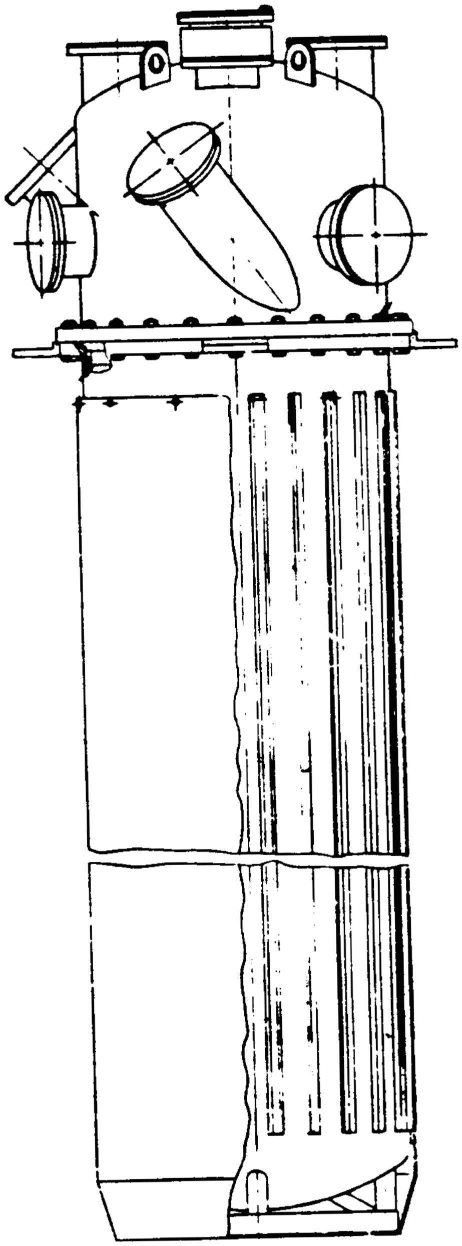


Figure 8. Test Chamber

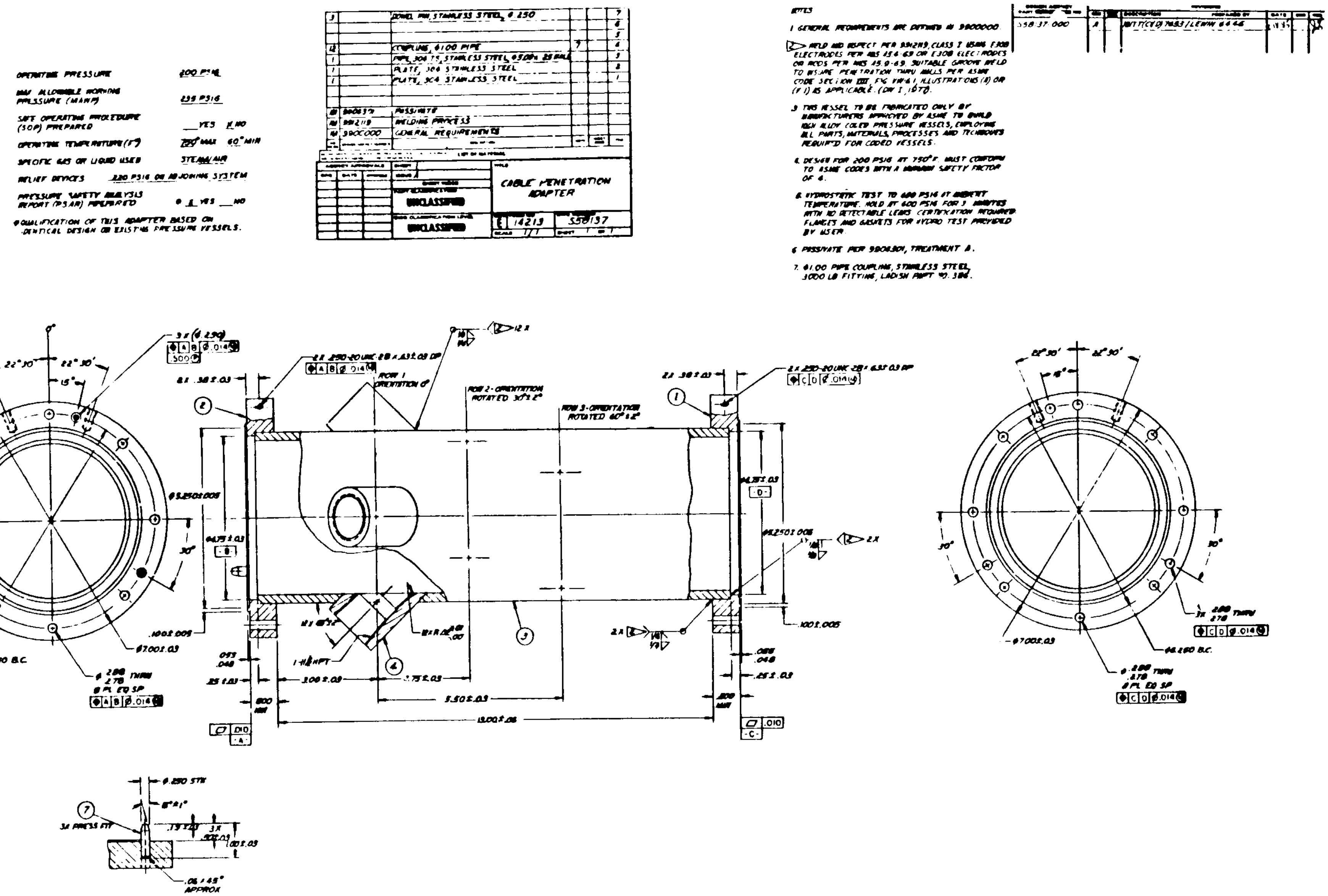


Figure 9. Cable Penetration Adapter for Multiconductor Cables

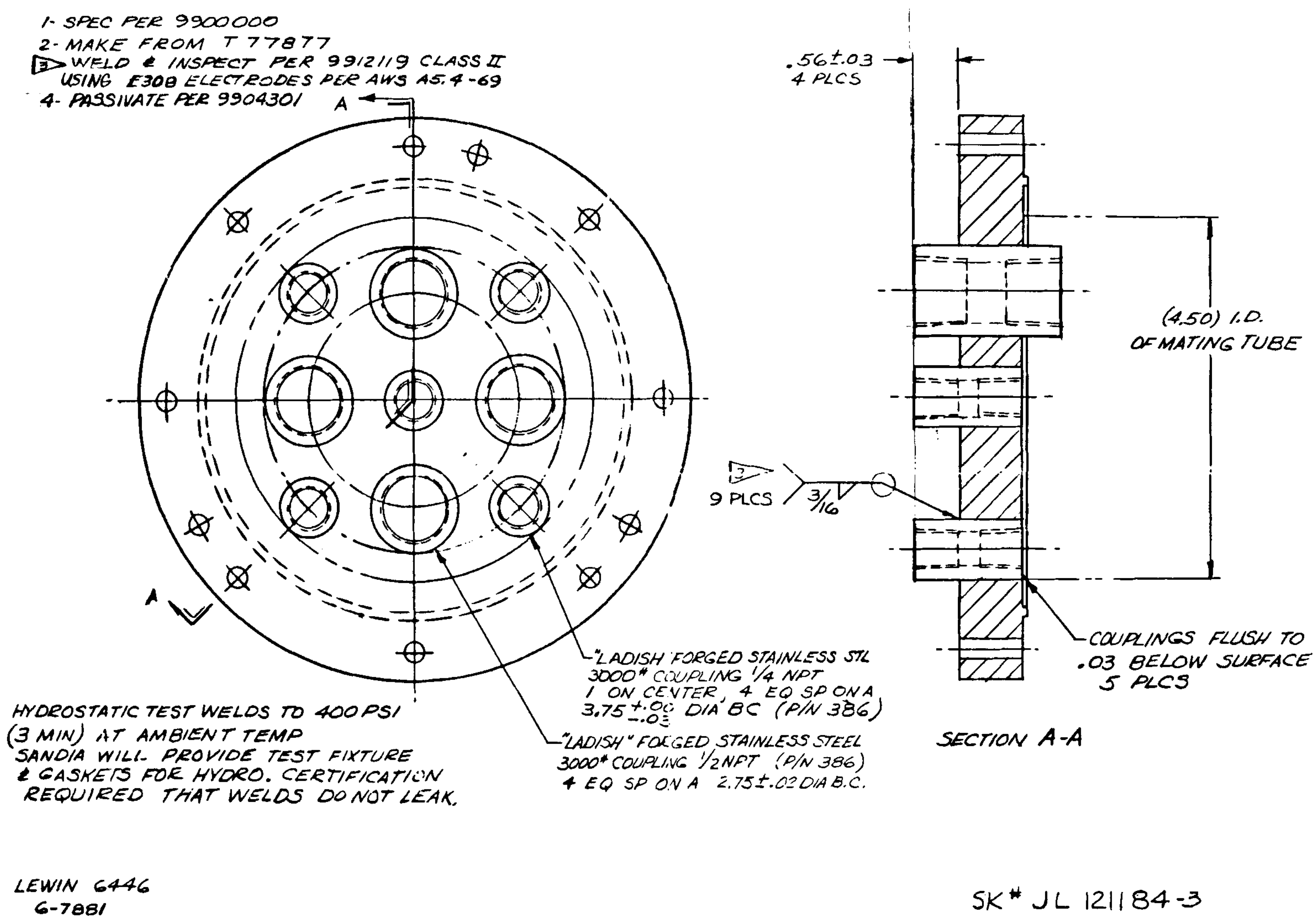


Figure 10. Flange for Single Conductors

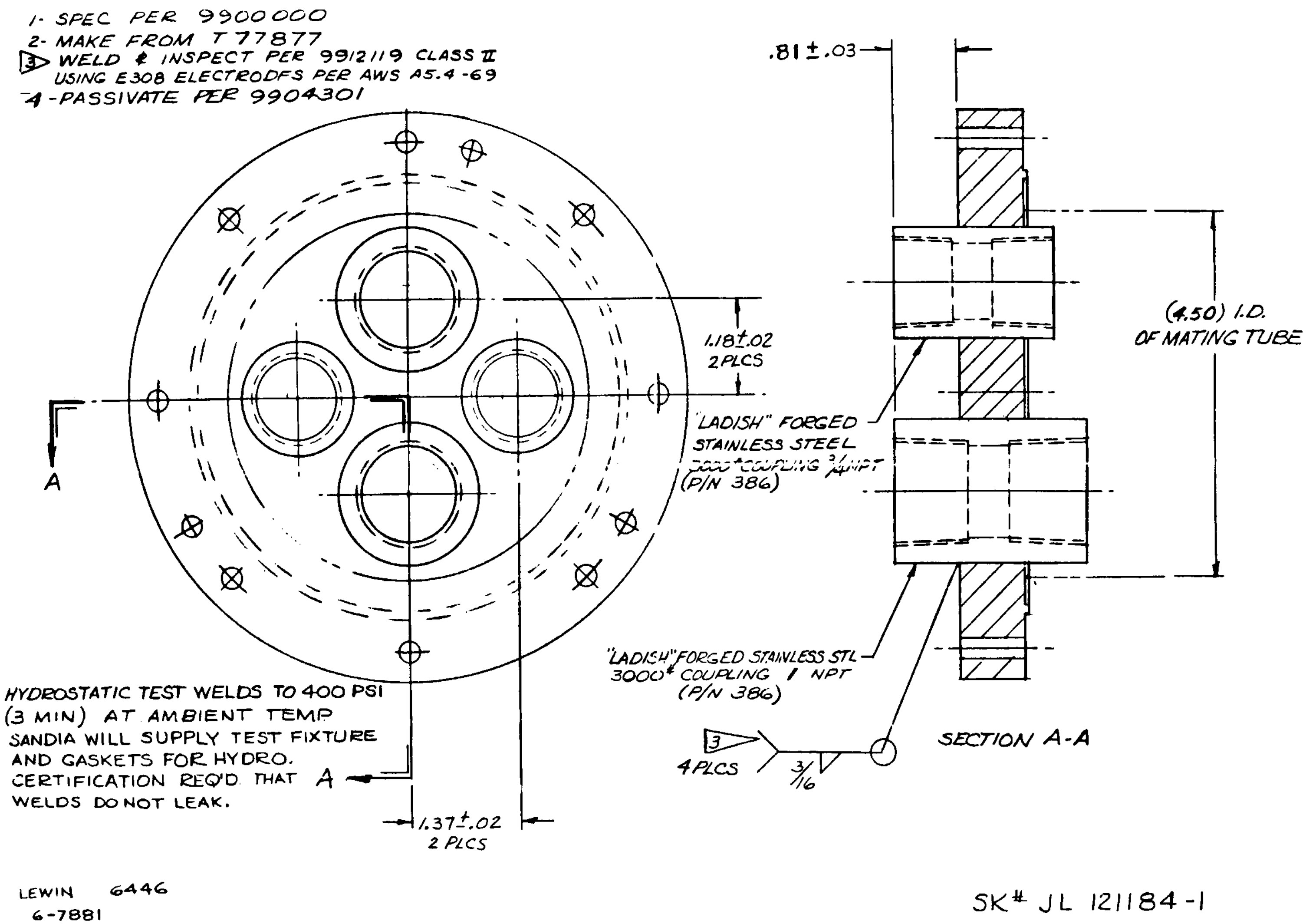


Figure 11. Flange for Unaged Cable

(1/16-inch) larger than the diameter of the cable, was drilled into the end-cap connector and the end-cap was tightened onto the stainless steel tube assemblies. The cable end was guided through the tube and emerged from the hole in the end-cap. By using electrical tape along the bottom of the end-cap and covering the bottom with putty, the assemblies were fixed into position and the tube was prevented from slipping along the cable length. Approximately 5 cm of cable was left exposed between the pipe coupling and male connector to allow the tube to hang vertically; thus, permitting the epoxy to fill the tube properly. With the cable centered in the tube, the tube was heated with a heatgun and the epoxy was allowed to slowly flow into the tube. Once the epoxy was within 0.64 cm of the top edge of the tube, filling was discontinued.

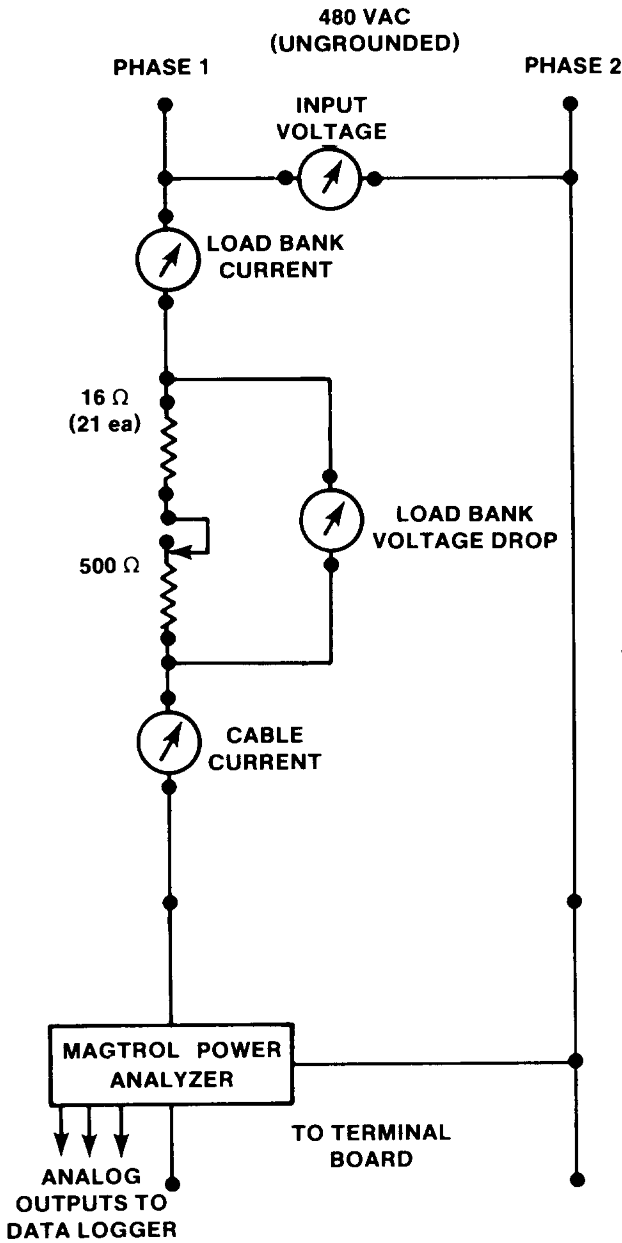
The epoxy was allowed to cure for approximately 24 hours. Then, the stainless steel tube assemblies were attached to the flange pipe couplings. (No sealing failures or steam leaks occurred from any of the assemblies.)

3.3.4 Energizing Cables During the HIACA Accident Simulation

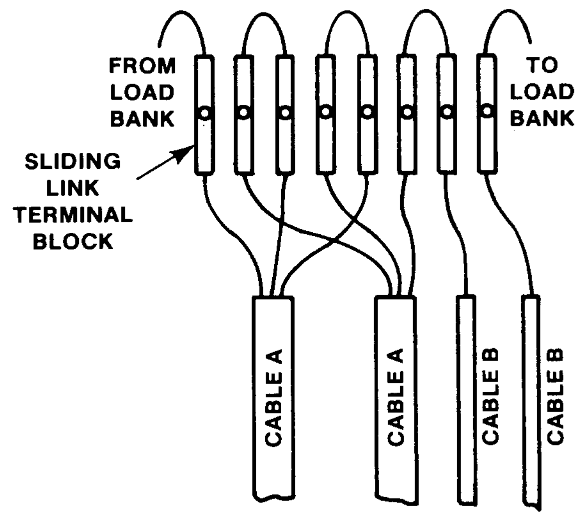
The cables were connected to a load-bank that was operated at 480 Vac, 60 Hz, and 0.57 A. Figure 12 includes a schematic of the system, as well as an illustration of a typical cable connection to the terminal blocks. A Magtrol power analyzer was used to monitor the load bank during the test. The current through the cables was limited to 0.6 A regardless of cable degradation. No active measurement of leakage current was taken because of the incompatibility of the data acquisition equipment with the 480 Vac circuit.

3.3.5 Data Acquisition and Instrumentation

The data acquisition system consisted of two Acurex Autodata Ten/10 dataloggers, one Acurex Autograph 800, 2 Hewlett Packard dual pen chart recorders, and one DEC PDP 11/23 laboratory computer. Datalogger "A" was dedicated for information necessary to properly operate the steam system. Datalogger "B" was used to monitor the chamber environment. The autograph unit was used to monitor the 40 Type K thermocouples installed in the regenerators in order to help evaluate the warm-up of the regenerators. One chart recorder was used to provide a constant record of the temperature and pressure profile of the environment for the experiment. The other was used to monitor steam system parameters such as accumulator pressure and flow, and steam flow.



TYPICAL CIRCUIT: 480 VAC
60 Hz, .57 AMPS
(3 ea)



TYPICAL MULTICONDUCTOR
AND SINGLE CONDUCTOR
TERMINATION

Figure 12. Load Bank/Terminal Block Configuration

The two dataloggers were connected to the computer via an RS-232 interface. The dataloggers were continuously scanning the channels and periodically outputting data to both the self-contained printers and the computer. The HIACA experiment monitoring program (HEMP) was used to receive and store the data on RL02 hard disc for data reduction at the end of the test. The computer was equipped with a dial-up modem capability to allow access to the data during unattended operations. The computer was only used to record data; the computer was not used for any control purposes.

The system instrumentation consisted of pressure transmitters, Type K thermocouples, Vortex flow meters, a pressure switch, and photodiode radiation detectors. Figure 7 shows the location of the pressure transmitters and thermocouples throughout the system and their datalogger and channel number designations. The pressure switch was used to monitor the HIACA hydraulic pump pressure and the datalogger channel was alarmed to provide a "loss of pump pressure" indication. The purpose of the photodiode detectors was to give a positive indication that a radiation field existed in the cell.

The experiment was instrumented with 36 Type K thermocouples, a pressure transmitter and a calibrated digital Heise gauge. The datalogger B was used to monitor the 36 thermocouples, the pressure transmitter and a magtrol power analyzer. (The magtrol power analyzer was used to monitor the current, voltage, and power applied to the cables.) Figure 13 shows the locations of the thermocouples installed in the chamber.

The equipment used during this experiment is listed in Appendix B. The manufacturer, model number, accuracy, and calibration data are included.

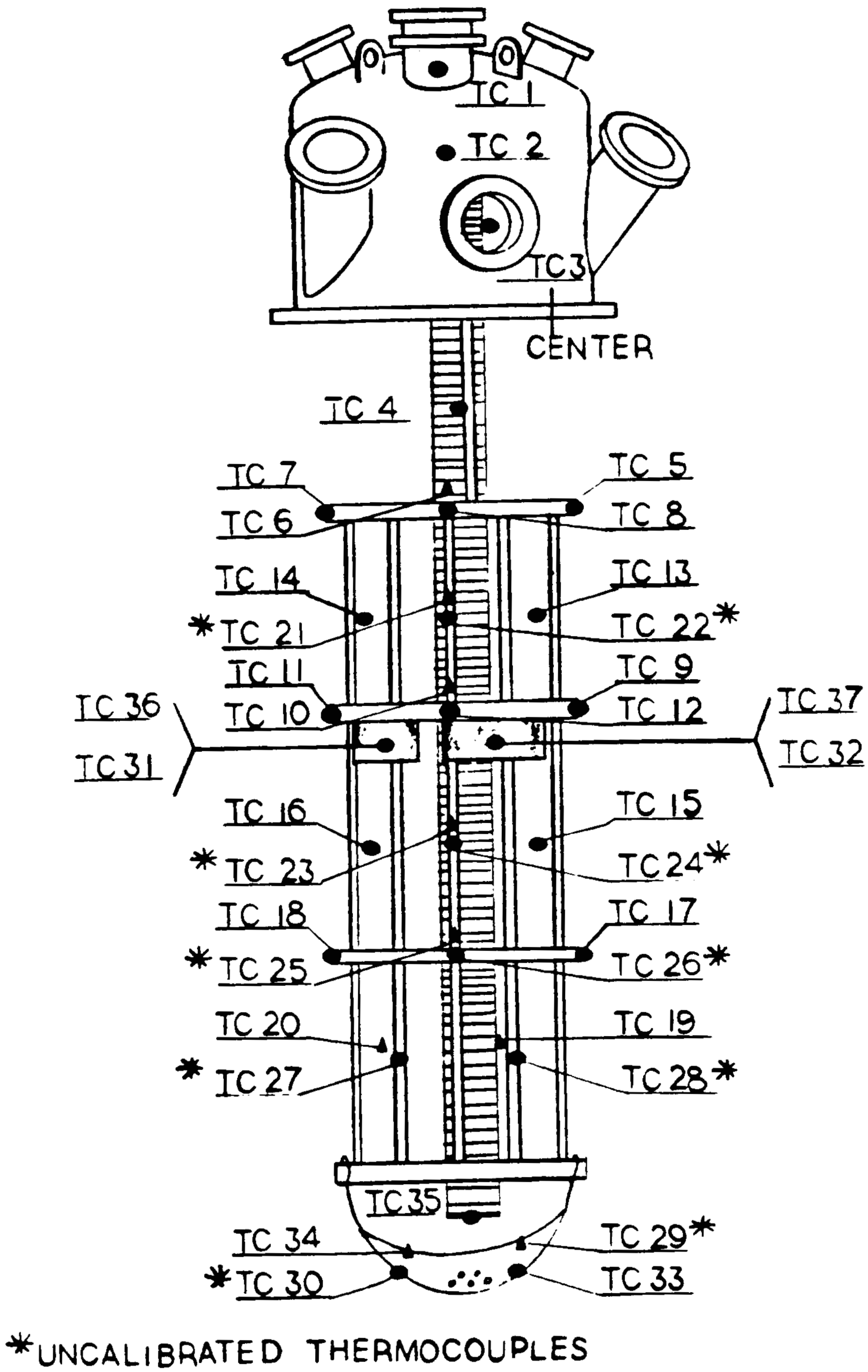


Figure 13. Thermocouple Locations

4. EXPERIMENT

4.1 Overview

A flow diagram of the experiment is shown in Figure 14. The superheated-steam experiment is divided into two parts. In Part I, virgin cables and insulation specimens were measured to obtain baseline data. The physical properties of the virgin cables and insulation specimens were measured and the tensile properties of the virgin insulation specimens were measured. This baseline data is listed in Table 6 for the following cables and insulation specimens: EPR D lot 1, EPR D lot 2, EPR F, EPR H, and EPR 1483 and the five variations of EPR 1483.

Part II involved the three subtests. Subtest 1 is shown in Boxes B, D, and E. In Box B, three cable products (EPR D lot 1, EPR D lot 2, and EPR H) and their corresponding insulation specimens were exposed to simultaneous radiation and thermal aging in the HIACA. The test conditions were 40 Mrad (at .27 Mrad/hr for 149 hrs) and 139°C for 167 hours. As shown by Box D, unaged cable and insulation specimens were added to the HIACA chamber prior to the accident simulation. The unaged cables included EPR D lot 1 and EPR H and the unaged insulation specimens included EPR D lot 1, EPR D lot 2, and EPR H. Box E identifies the simultaneous radiation and steam accident simulation in the HIACA. The 21-day accident profile included approximately 110 Mrad (at three different dose rates) and a steam environment with two transients (maximum temperature of 171°C and maximum pressure of 448 kPa (65 psig)). As shown in Figure 14, the materials in Boxes B and D were exposed to the accident profile (Box E).

Subtest 2 is shown in Boxes A and E of Figure 14. In Box A, EPR D lot 1 and EPR F insulation specimens were exposed to simultaneous aging in the LICA. Although the specimens were exposed to the same equivalent age, the insulation specimens were exposed to five different simultaneous thermal and radiation aging conditions using progressively lower temperatures (155°C to 103°C) and lower dose rates (765 krad/hr to 16 krad/hr). The aged insulation specimens from Box A and corresponding unaged insulation specimens were exposed to the accident simulation (Box E).

Subtest 3 is shown in Boxes C and E of Figure 14. In Box C, EPR 1483 and five variations of EPR 1483 were subjected to simultaneous aging. The aging conditions were 50 Mrad/hr (300 krad/hr) and 141°C for 167 hours. The aged insulation specimens from Box C and corresponding unaged insulation specimens were exposed to the accident simulation (Box E).

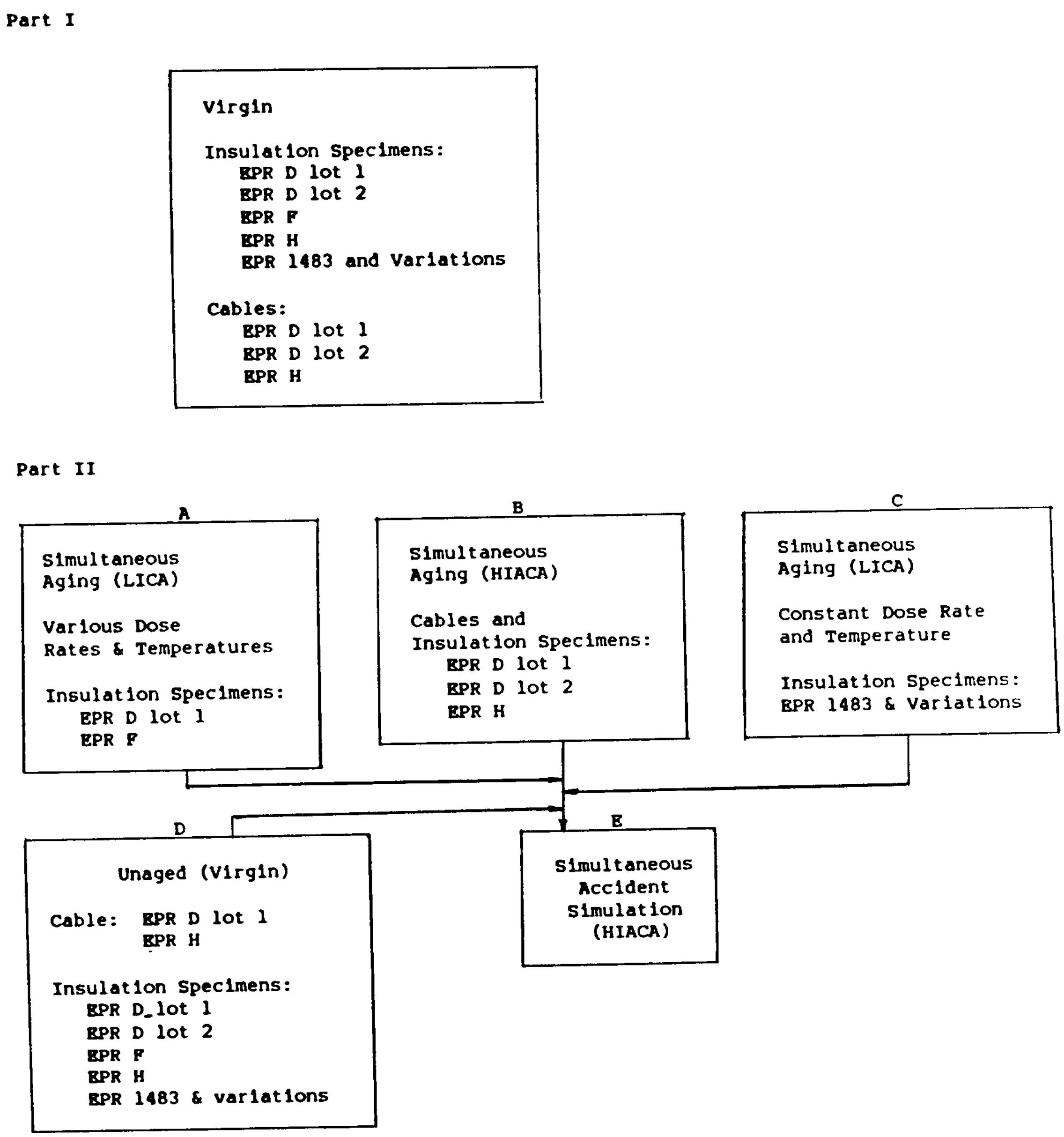


Figure 14. Flow Diagram of the Experiment

Table 6

Virgin Insulation Specimens

A. Virgin Cables: Diameter (cm)

	Multiconductor	Multiplex	Single Conductor
EPR D lot 1	1.10	.79	.43
EPR D lot 2	1.08	None	.40
EPR H	1.18	.84	.41

B. Virgin Insulation Specimens:

	EPR D lot 1	EPR D lot 2	EPR F	EPR H
Ave. weight (g)	1.32	1.40	2.01	1.39
Length (cm)	11.13 ± .11	11.18 ± .18	11.07 ± .14	11.13 ± .11
Outside diameter (cm)	.40 ± .003	.40 ± .02	.47 ± .003	.41 ± .002
T_o (N)	118.8 ± .89	125.12 ± 3.6	160.7 ± 4.4	89.8 ± 3.0
e_o (%)	229.3 ± 4.04	245.5 ± 9.54	361.67 ± 10.41	241.75 ± 12.34

C. EPR 1483:

Batch	1	2	3	4	5	6
weight (g)	1.88	1.65	1.95	1.84	2.53	1.83
length (cm)	10.97 ± .11	10.92 ± 0	10.92 ± 0	10.92 ± 0	10.92 ± 0	10.92 ± 0
thickness (cm)	.21 ± .01	.20 ± .02	.21 ± .002	.21 ± .02	.29 ± .02	.21 ± .01
width (cm)	.66 ± .02	.64 ± .02	.64 ± .01	.63 ± .01	.65 ± .02	.67 ± .02
T_o (N)	146.3 ± 9.0	141.6 ± 14.6	150.3 ± 10.7	145.5 ± 4.4	196.2 ± .6	105.3 ± 4.4
e_o (%)	222.25 ± 16.54	189.0 ± 27.8	184.80 ± 19.83	192. ± 18.55	160. ± 25.46	284.66 ± 11.68

Part II of the experiment will be discussed in greater detail and in chronological order in Sections 4.2 through 4.10.

4.2 LICA Aging of Insulation Specimens

The LICA facility was last calibrated on August 8, 1984. Therefore, the decay rate of Co^{60} was used to establish correct dose rates for November 1, 1984. These dose rates were calculated for the South Linear Array and the Circular Array. For further details, see Section 3.1.

The insulation specimens were aged in LICA cans located in the South Linear Array and the Circular Array. Each LICA can had an air flow rate of 60 cc/min. In addition, each LICA can was rotated 180° after 25 Mrad to minimize the effects of radiation gradients.

The insulation specimens were divided into two groups: (1) EPR D lot 1 and EPR F and (2) EPR 1483 and five variations of the EPR 1483 formula.

EPR D lot 1 and EPR F

The EPR D lot 1 and EPR F samples were placed in separate LICA cans to avoid possible outgassing effects from one type of insulation to the other. These insulation specimens were then exposed to five different aging exposures, as shown in Table 7. The dose rates, temperatures, and desired exposure times were calculated using the Arrhenius Equation. Some insulation specimens from each batch were removed at 25 Mrad while the rest were removed after 50 Mrad. Each different batch was exposed to the same equivalent age: (1) 25 Mrad and 20 years at 55°C or (2) 50 Mrad and 40 years at 55°C (assuming a 1.04 eV activation energy).

EPR 1483 and five variations

The strips of EPR 1483 and the five variations (Batches 1-6) were placed in separate LICA cans to avoid possible outgassing effects from one type of insulation to the other. Each formulation was exposed to 300 Krad/hr at 141°C for 167 hours, as shown in Table 7. The dose rates, temperatures, and desired exposure times were calculated using the Arrhenius Equation. Some insulation specimens from each batch were removed at 25 Mrad while the rest were removed after 50 Mrad. Each different batch was exposed to the same equivalent age: (1) 25 Mrad and 20 years at 55°C or (2) 50 Mrad and 40 years at 55°C (assuming a 1.04 eV activation energy).

Table 7

LICA Aging for EPR D and EPR F Insulation Specimens

Batch	Dose Rate (krad/hr)	Temperature (°C)	Calculated Time for 40 year Equivalent Aging (hr)	Actual Exposure Time (hr)	Actual Total Dose (Mrad)	Actual Accelerated Aging (yr)
1	765	155	65.4	65	49.7	40.2
2*	300	141	166.7	168	50.4	40.0
3	107	127	467.3	464	49.6	39.9
4	50	117	1000	1004	50.2	39.8
5	16	103	3125	3124	50.0	39.1

*Same conditions for all variations of EPR 1483.

4.3 HIACA Test Setup and Visual Examination of Cables

The cables used in the superheated-steam test are described in Table 8. Hereafter, these cables will be identified by the "cable designator."

First, the cables were visually inspected to assure that no handling damage occurred when the multiplex and single conductors were prepared. Then, each cable was wrapped three times around the outside of a HIACA mandrel. Three mandrels were needed to mount all of the cables. The cable sequence, from the top to the bottom of each mandrel (Table 9), was chosen to minimize the chance of exposing duplicate cables to any environmental problems that might occur in one section of the chamber.

Table 8

Cable Designators

Cable Designator	Description
A	EPR D lot 1: aged multiconductor
B	EPR D lot 1: aged multiconductor
C	EPR D lot 1: unaged multiconductor
D	EPR D lot 1: unaged multiconductor
E	EPR D lot 2: aged multiconductor
F	EPR D lot 2: aged multiconductor
G	EPR D lot 1: aged multiplex
H	EPR D lot 1: aged single conductor
I	EPR D lot 2: aged single conductor
J	EPR H: aged multiconductor
K	EPR H: aged multiconductor
L	EPR H: unaged multiconductor
M	EPR H: unaged multiconductor
N	EPR H: aged multiplex
O	EPR H: aged single conductor

Table 9

Order of Cables on the Mandrels

Mandrel #1	Mandrel #2	Mandrel #3
O	G	D
I	N	M
H	E	C
F	J	L
K	A	
B		

Then, the first two mandrels were installed in the HIACA chamber. (The third mandrel was used for the "unaged" cables: C, D, L, and M.) The cable leads were spiraled up the inside of the mandrels through the exit ports and connected to terminal blocks. At this point in the experiment, the cables were examined for signs of cracks or sharp bends. No cracks or sharp bends were evident. (If cracks or sharp bends had been found, the cable would have been replaced.) The cables are shown in Figure 15.

4.4 Baseline Tests

The chamber was filled with tap water with a conductivity of 409 ohms/cm and a pH of 5.8. After the cables soaked for one hour, IR and AC leakage current measurements were taken. The effective water length of each cable is given in Table 10. (The "effective water length" is the length of cable that was submerged.)

Table 10

Effective Cable Length

Cable	Effective Water Length (meter)	Effective Steam Length (meter)
A	5.46	6.82
B	3.70	5.26
C	5.16	6.36
D	4.83	6.08
E	5.08	6.64
F	3.45	4.80
G	4.00	5.81
H	3.36	4.77
I	3.30	4.71
J	4.33	5.68
K	3.60	4.95
L	5.28	6.43
M	5.02	6.22
N	4.11	5.93
O	3.25	4.66

error: ± .15 m

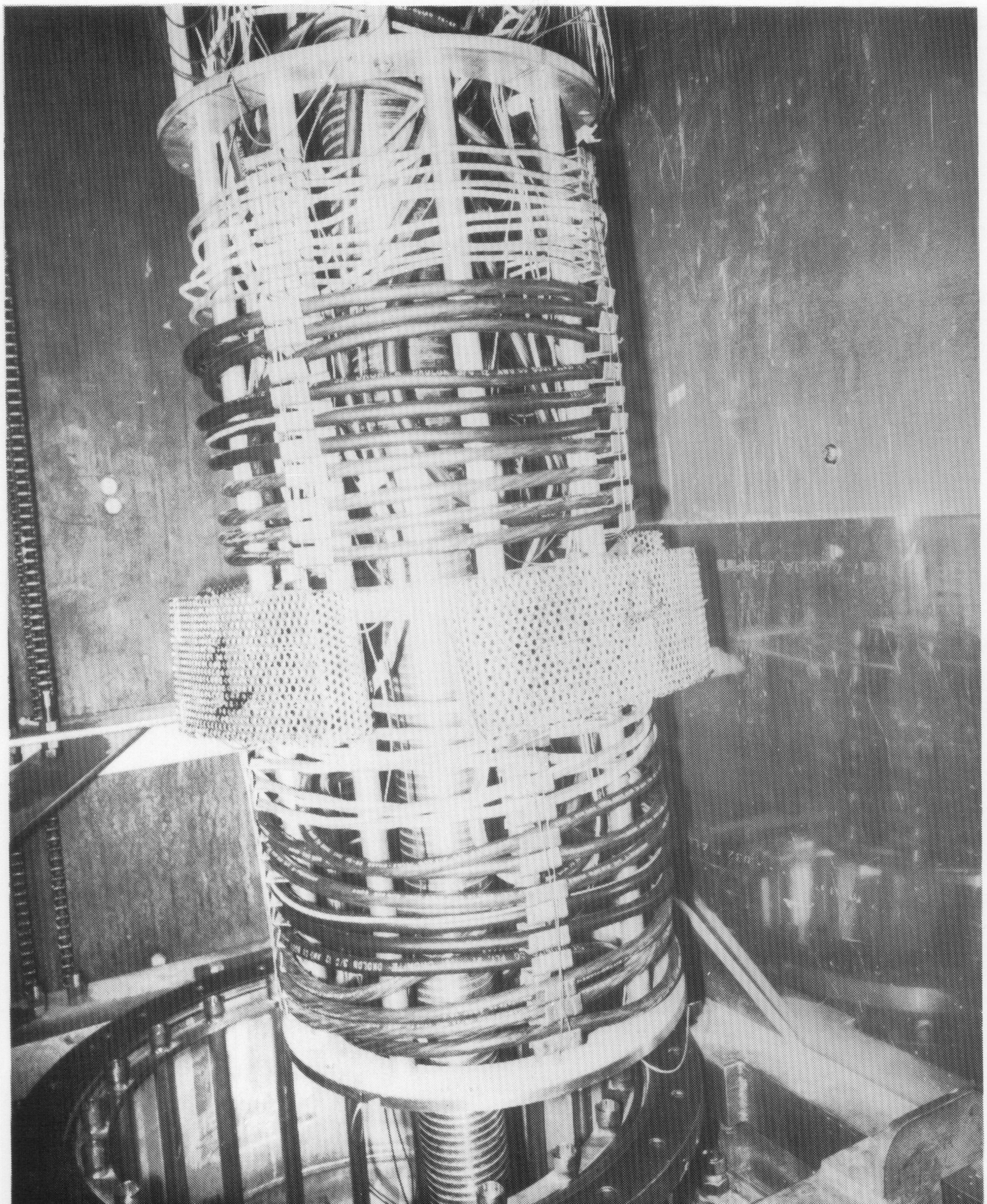


Figure 15. Virgin Cables on Mandrels

The IR measurements were taken after one minute at 500 V. Measurements were taken for each conductor to ground and one conductor to conductor. If different values were found between conductor to ground measurements for one cable or between identical cables, the measurements were retaken. Also, the measurements were repeated for all single conductors. For all cables, IR values of 1.0×10^{11} ohms or greater were measured between each conductor and ground.

AC leakage current measurements were taken after one minute at 600 V. Every conductor to ground was measured. If different values were found between conductor to ground measurements for one cable, the measurements were retaken. Also, the measurements were repeated for all single conductors. For all cables, AC leakage current values of 0.45 to 0.64 mA were measured between each conductor and ground.

IR and AC leakage current measurements taken throughout the test are listed in Appendix C and Appendix D, respectively.

4.5 Addition of Insulation Specimens

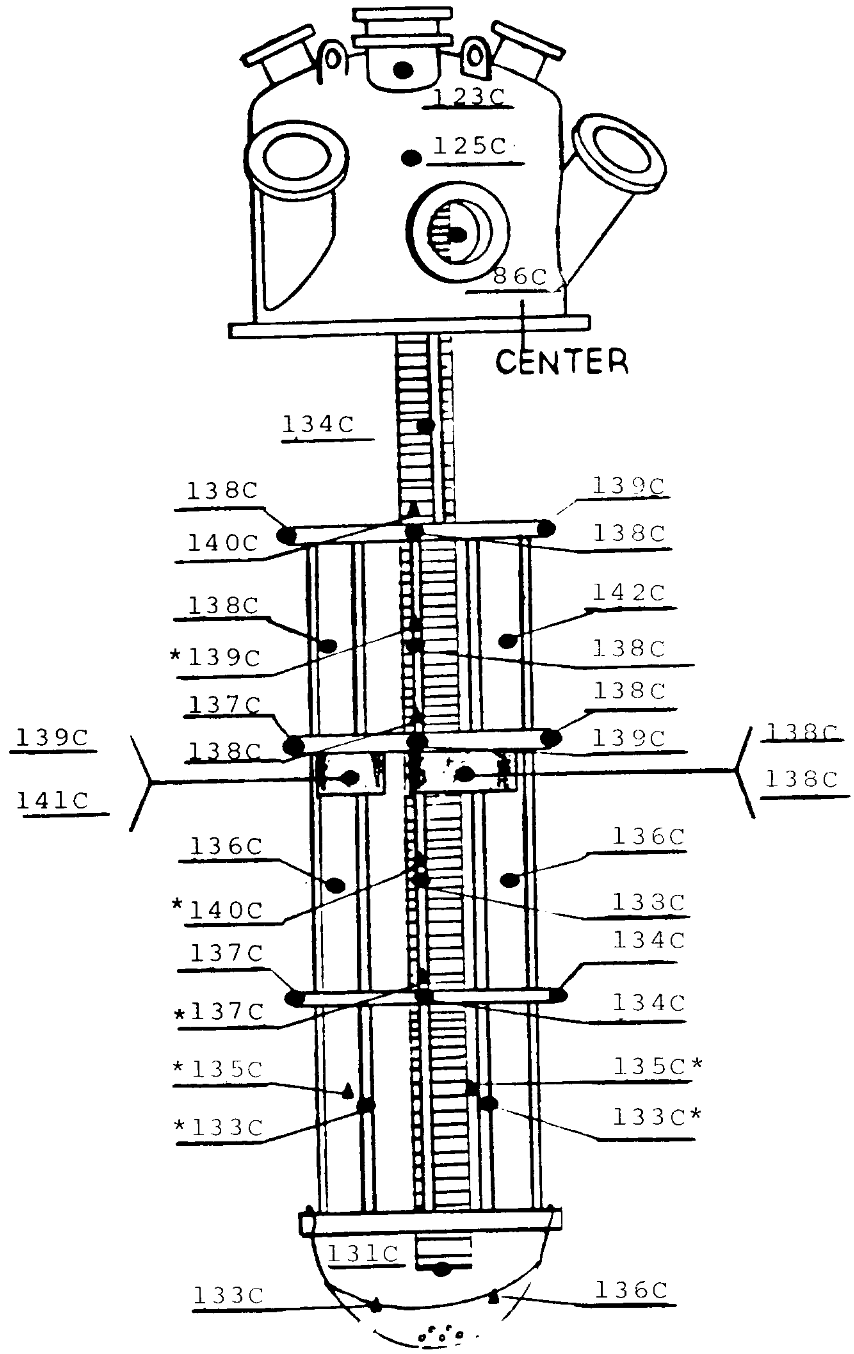
After the IR and AC leakage current measurements were completed and the chamber was drained, EPR D lot 1, EPR D lot 2, and EPR H insulation specimens were placed in the HIACA baskets. The four HIACA baskets (two baskets shown in Figure 15) surround the mandrels and are located between mandrels #1 and #2.

4.6 Simultaneous Aging

The cables and insulation specimens (identified in Section 4.3) were exposed to simultaneous thermal and radiation aging. The aging conditions were designed to simulate cable aged for forty years at 55°C and exposed to a total dose of 40 Mrad.

By using the Arrhenius equation and an activation energy of 1.04 ev, the accelerated thermal aging conditions were calculated to be 139 ± 5°C for 168 hours. The achieved conditions were 139 ± 5°C for 167 hours and the chamber temperature did not exceed 144°C. Figure 16 shows a sample of chamber temperatures in different sections of the chamber. The time for thermal aging was adjusted to include only the time when the chamber was between 139 ± 5°C. For example, the temperature stabilized to within 139 ± 5°C after three hours. (Deviations are listed in Appendix E.)

Dose rates for each group of HIACA cobalt (Co^{60}) pencils were last determined on November 10, 1980. By using the decay rate of Co^{60}, new dose rates were calculated for July 26, 1985. Because of differences in the total time



*UNCALIBRATED THERMOCOUPLES

Figure 16. Chamber Temperatures During the Simultaneous Aging Exposure on August 6, 1985 at 09:00

required to achieve the total dose and thermal exposure, it was necessary to perform part of the thermal exposure without concurrent radiation exposure. However, in order to maintain irradiation during most of the thermal exposure, five groups of pencils were used which provided a dose rate of 0.269 Mrad/hr. The radiation began after the thermal aging temperature had stabilized. The radiation exposure was for 149 hours, but not for 149 consecutive hours. This led to a total dose of 40.1 Mrad. (Deviations are listed in Appendix E.)

4.7 Visual Inspection, Insulation Specimens Removed, and Baseline Tests Repeated

After the aging exposure, the cables were visually inspected. Although no cracks or sharp bends were observed, a white film was present on the exterior of the chlorinated polyethylene jacket (cables A, B, E, and F). For cables A and F, the jacket of one wrap appeared to be stuck to the jacket of another wrap. However, after the cables air-dried overnight, the cables wraps separated. In addition, cables F and H were touching thermocouple wires. The thermocouple wires were moved and a slight indentation on the outer surface of cable H was noted. The aged cables are shown in Figure 17.

All insulation specimens were removed prior to repeating the baseline tests, as explained in Section 4.4. The resulting IR and AC leakage current values were similar to the baseline values. The exact values are given in Appendices C and D.

4.8 Addition of Unaged Cables, Visual Inspection, Baseline Tests Repeated, and Addition of Insulation Specimens

After completing the baseline tests described in Section 4.7, the chamber was drained and the third mandrel was installed in the HIACA chamber. The cables leads spiraled up the outside of the mandrels through the ports and were connected to terminal blocks. These cables were visually inspected to ensure that no sharp bends or cracks exist.

Again, the baseline tests discussed in Section 4.4 were repeated. Since the IR and AC leakage current values for each cable were similar to the previous baseline values, it would appear that no handling damage had occurred.

After these measurements were completed, insulation specimens that had been exposed to the HIACA aging and additional insulation specimens, were placed in HIACA baskets and the chamber was reclosed. These insulation

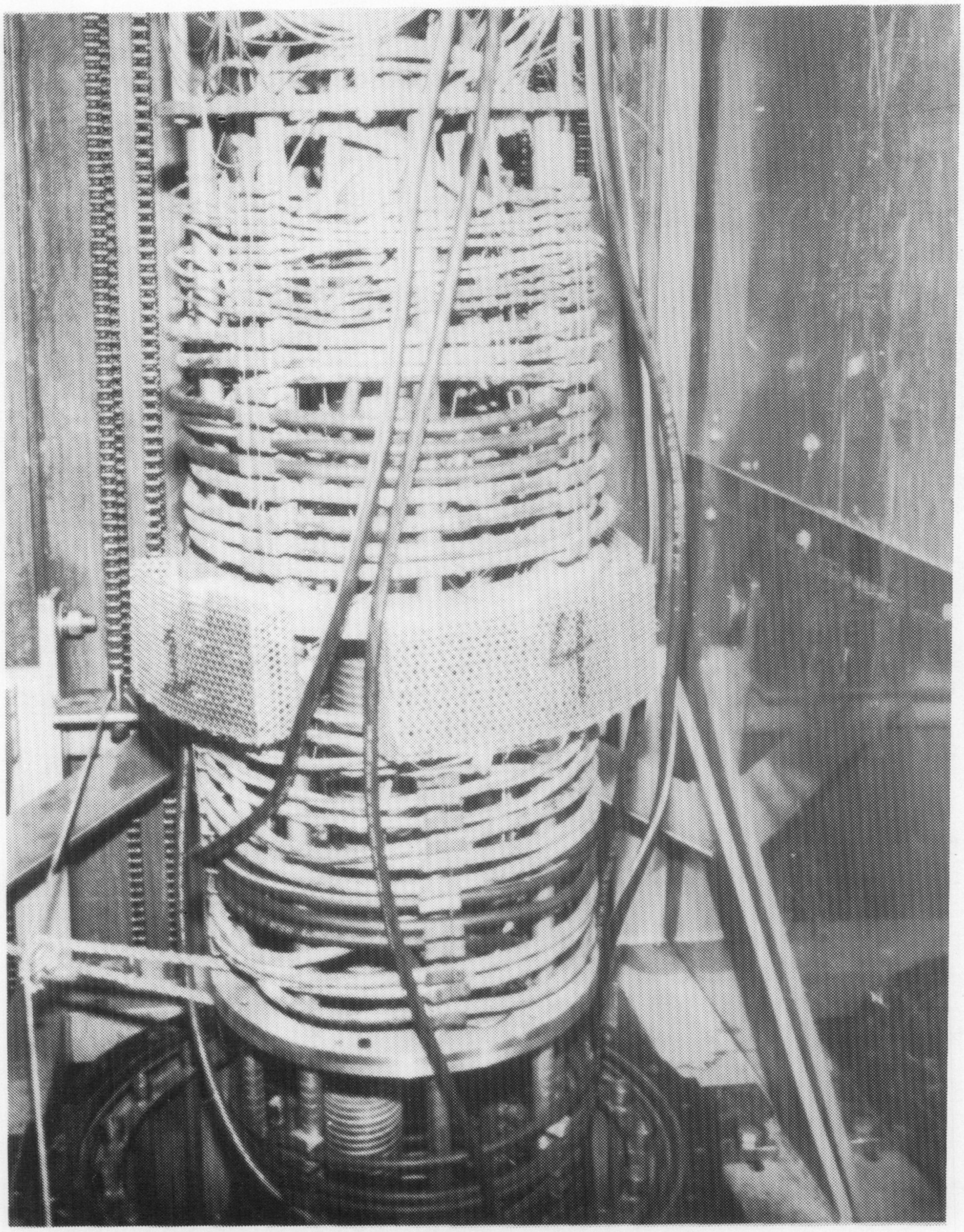


Figure 17. Aged Cables

specimens included: EPR D lot 1, EPR D lot 2, and EPR H from the HIACA aging; Batches 1-5 of EPR D lot 1 and EPR F from the LICA aging; Batches 1-6 of EPR 1483 from the LICA aging; and unaged EPR D lot 1, EPR D lot 2, EPR F, EPR H, and Batches 1-6 of EPR 1483.

4.9 Superheated-Steam Test Accident Environment

The 21-day superheated-steam test accident environment included a simultaneous radiation exposure (approximately 110 Mrad) and temperature and pressure conditions similar to the profile in IEEE 323-1974. The cables were energized at 480 V and .6 A throughout the accident exposure. The intended profile is shown in Figure 18.

Although the superheated-steam test accident environment differed slightly from accident environments in qualification tests by manufacturers and utilities, the superheated-steam test conditions generally are similar or less severe than those used by the cable industry. For example, the differences between the accident environment of the superheated-steam test and the qualification test, by the manufacturer of EPR D, are as follows:

1. Superheated-steam test: cables loaded at 0.6 A
   Qualification test: cables loaded to $\geq$ 10 A,

2. Superheated-steam test: 2 transient steam ramps
   Qualification test: 1 transient steam ramp,

3. Superheated-steam test: P_{max} = 448 kPa (65 psig); T_{max} = 171°C
   Qualification test: P_{max} = 448 kPa (65 psig); T_{max} = 196°C,

4. Superheated-steam test: no chemical spray
   Qualification test: chemical spray during part of the accident simulation.

Dose rates for each group of HIACA Co^{60} pencils were last determined on November 10, 1980. By using the decay rate of Co^{60}, new dose rates were calculated for August 26, 1985. In order to simulate a total dose of approximately 110 Mrad, three different groups of Co^{60} pencils were chosen: 7 groups, 4 groups, and 2 groups. Because of radial uniformity, even with two groups of pencils, no rotation of the pencils was needed (Reference 3).

A total accident dose of approximately 108 Mrad was obtained by using three different dose rates: 0.37 Mrad/hr for 7 days, 0.21 Mrad/hr for 4 days, and 0.11 Mrad/hr for 10 days. (Deviations are listed in Appendix E.)

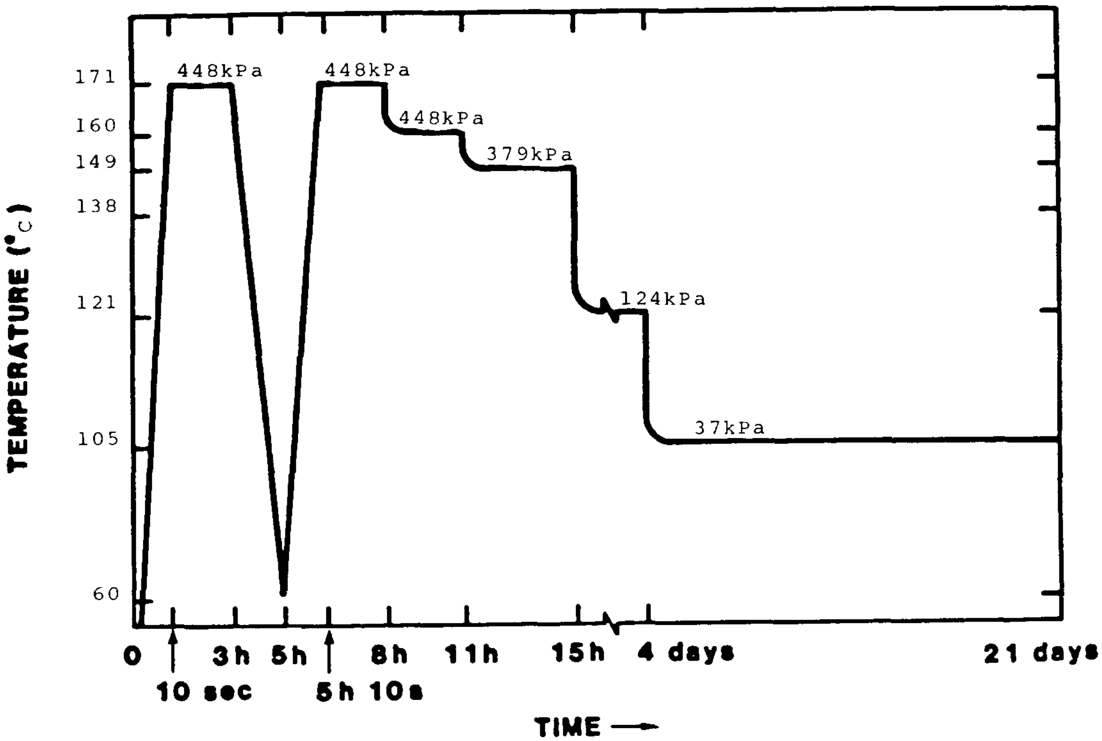


Figure 18. Intended Temperature and Pressure Profile for Accident Simulation

Table 11 shows the cable test ramp requirements (pressures and temperatures as a function of time) to simulate the accident profile in the HIACA facility. In Figures 19 and 20, the achieved profile and the intended profile are shown. These figures show that the achieved profile closely matched the intended profile.

IR measurements were taken at the maximum temperature of each transient and during each temperature plateau: 160°C, 149°C, 121°C, and 105°C. (IR measurements were taken every two to three days during the 105°C plateau.) The IR measurements were taken after one minute at 500 V. If the IR measurements were less than the capacity of the machine (1.0×10^6), then the measurement was repeated at a lower voltage.

Several cables (Cables A, B, D, E, F, G, H, I, and N) had water dripping from the conductor during parts of the accident exposure. Although each cable remained energized throughout the accident exposure, cables A and B had very low IR readings ($< 1.0 \times 10^5$ ohms at 50 V) between day 19 and day 21 of the accident. The complete list of IR measurements is given in Appendix C.

Throughout the accident exposure, all cables were loaded at 480 Vac and 0.6 A. During this time, the load circuit did not trip even though cables A and B were degrading. This result was expected for two reasons: (1) the load circuit was not designed to trip; the current flow was limited by load resistors to 600 mA and (2) without chemical spray or water spray, the path between the insulation and ground was a rather pure steam environment. (This path is not very conducting. Therefore, insulation failures may not be evident until the posttest IR and AC leakage current measurements using tap water as a conducting medium.)

4.10 Posttest Examination

After the accident exposure, the chamber was opened and the cables were visually examined. Insulation specimens were removed from the baskets and measured, within 24 hours, for dimensional changes and weight gain. When the percent weight increase was below 10 percent, the insulation specimens were tensile tested. (Immediately after the accident simulation, the insulation specimens had absorbed too much moisture to fit between the jaws of the tensile testing equipment.)

Once again baseline tests, described in Section 4.4, were repeated. Additional AC leakage current measurements were

Table 11

Cable Test Ramp Requirements for the Accident Simulation

Time	Pressure (kPa)	Temperature (°C)	Condition
0	0	Ambient	Saturated
10-15 sec	448	154	Saturated
30 sec - 1 min	448	171	Superheated
3 hr	448	171	Superheated
3 hr 5 min	448	154	Saturated
10 min	427	153	Saturated
15 min	407	151	Saturated
20 min	386	149	Saturated
25 min	365	148	Saturated
30 min	345	146	Saturated
35 min	324	144	Saturated
40 min	303	143	Saturated
45 min	283	141	Saturated
50 min	262	138	Saturated
55 min	241	137	Saturated
4 hr	221	134	Saturated
4 hr 5 min	200	132	Saturated
10 min	179	129	Saturated
15 min	159	127	Saturated
20 min	138	124	Saturated
25 min	117	121	Saturated
30 min	97	117	Saturated
35 min	76	113	Saturated
40 min	55	109	Saturated
45 min	34	104	Saturated
50 min	0	95	Saturated
55 min	0	95	Saturated

Table 11

Cable Test Ramp Requirements (cont'd)

Time	Pressure (kPa)	Temperature (°C)	Condition
5 hr	0	95	Saturated
5 hr 10-15 sec	448	154	Saturated
5 hr 30 sec-1 min	448	171	Superheated
8 hr	448	171	Superheated
8 hr 45 min	448	160	Superheated
11 hr	448	160	Superheated
11 hr 5 min	448	154	Saturated
10 min	414	152	Saturated
15 min	379	149	Saturated
15 hr	379	149	Saturated
5 min	345	146	Saturated
10 min	310	143	Saturated
15 min	276	140	Saturated
20 min	241	137	Saturated
25 min	207	132	Saturated
30 min	172	128	Saturated
35 min	138	123	Saturated
40 min	124	121	Saturated
4 Days	124	121	Saturated
5 min	103	118	Saturated
10 min	69	112	Saturated
15 min	37	105	Saturated
21 Days	37	105	Saturated
5 min	0	Ambient	Saturated

* End of Test *

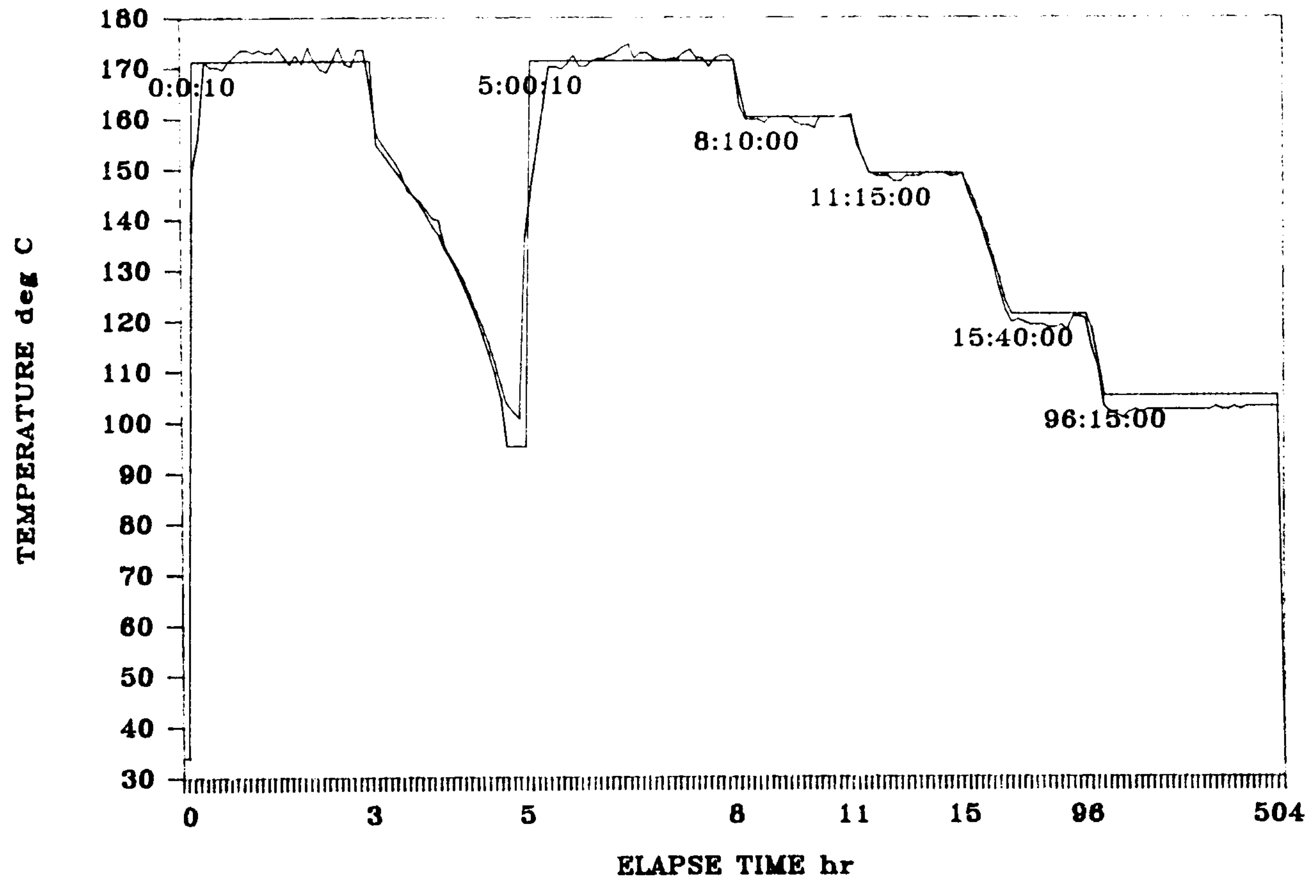


Figure 19. Superheat Cable Test: Intended and Actual Temperatures

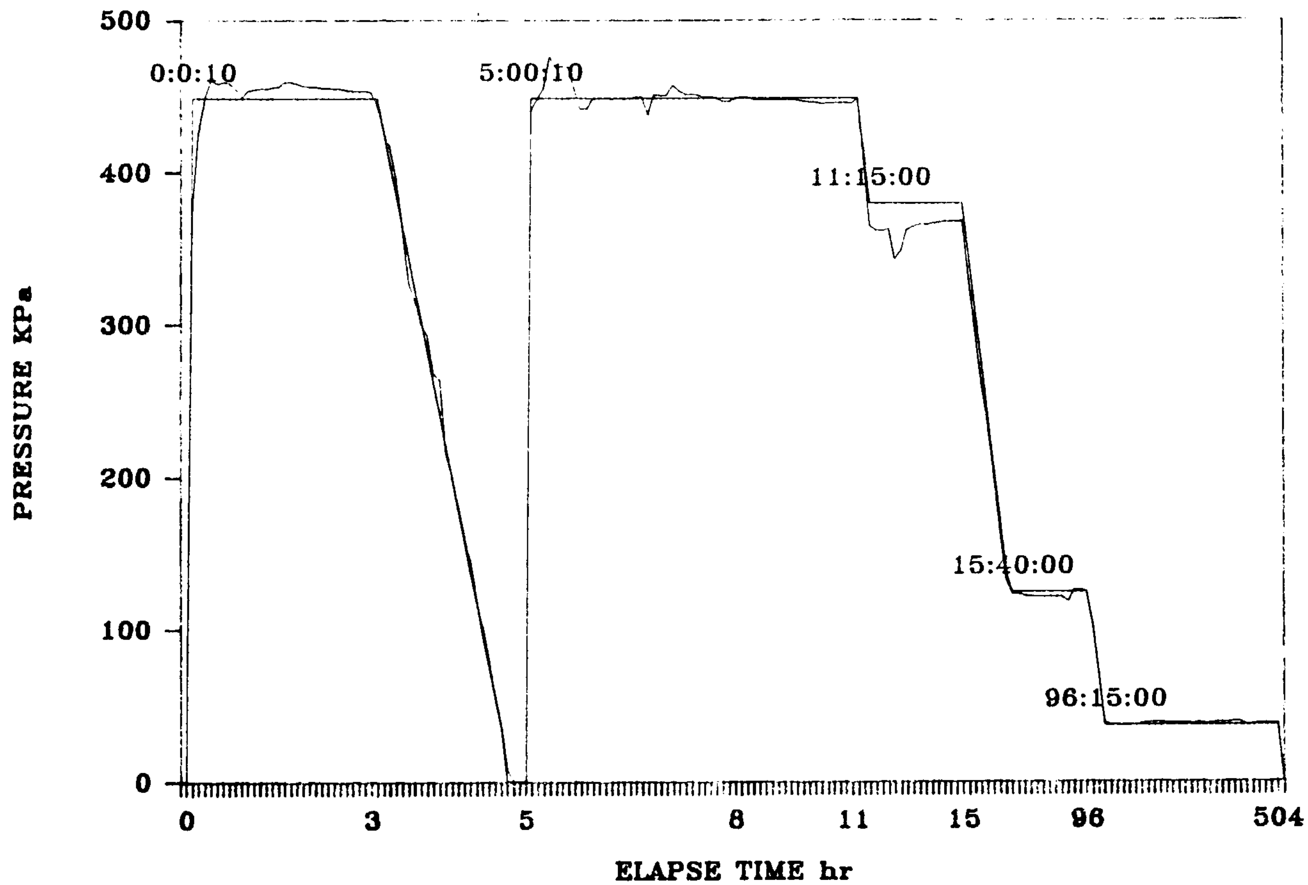


Figure 20. Superheat Cable Test: Intended and Actual Pressures

made: after one minute at 1200 V, after one minute at 1800 V, and after five minutes at 2400 V. These tests took four days. All cables, except A and B, were subjected to each test. Cables A and B failed the AC leakage current test at 1800 V.

At the conclusion of the IR and AC leakage current tests, the cables were reexamined and photographed as shown in Figure 21. In addition, the circumference of each cable was measured; the powder found on the jacket of cables A, B, E, and F was chemically analyzed; and the chlorine and bromine content was determined for virgin jacket and/or insulation samples of EPR D lot 1, EPR D lot 2, EPR F, and EPR H.

The results of the posttest examination are described in detail in Section 5.0.

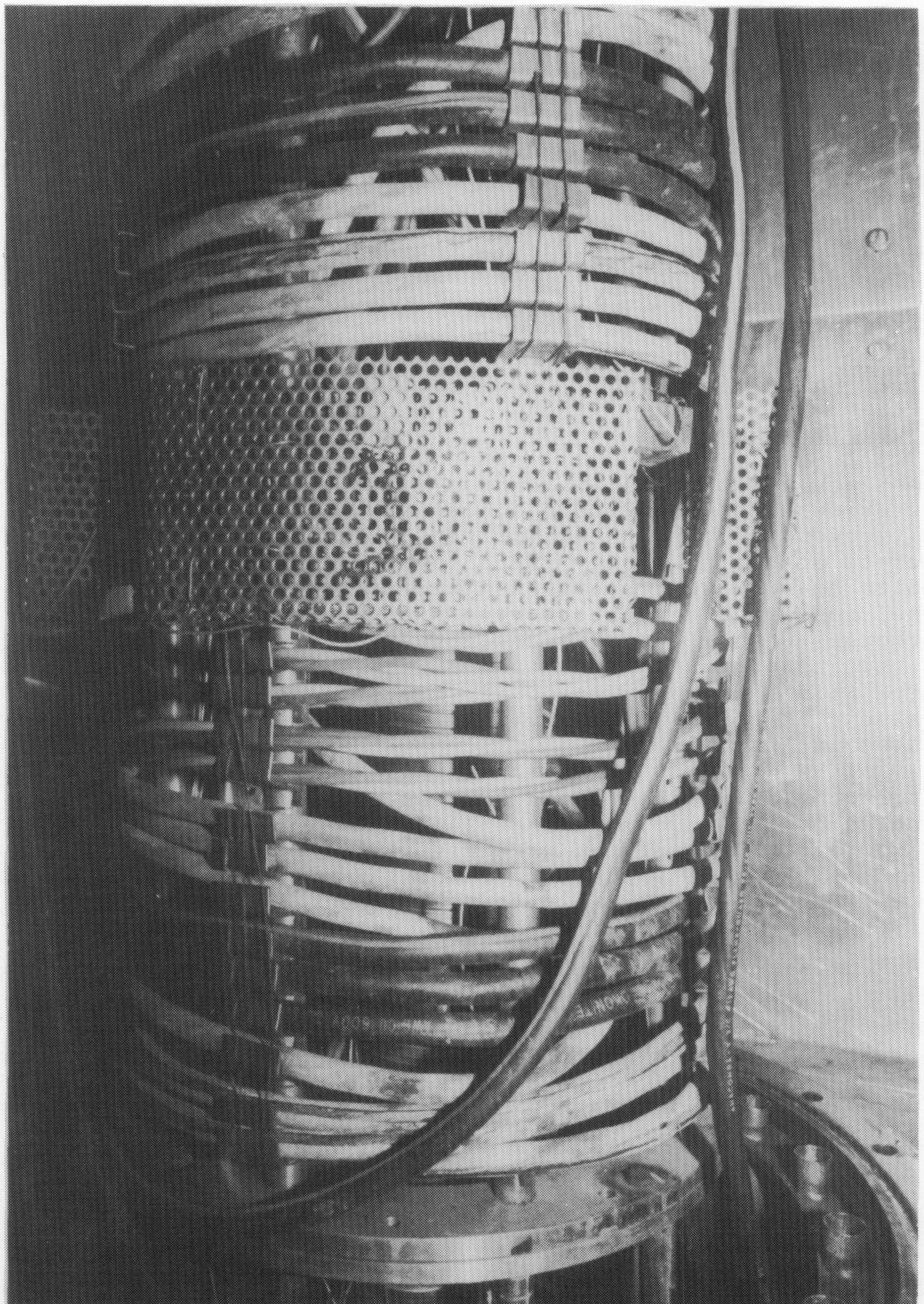


Figure 21. Posttest Cables

5. RESULTS OF THE POSTTEST EXAMINATION

Sections 5.1 to 5.5 describe the results of the posttest examination, in detail, for each EPR product: EPR D lot 1, EPR D lot 2, EPR F, EPR H, and EPR 1483. Each section includes (1) visual examination, circumferential measurements, IR measurements, AC leakage current measurements, and chemical analysis for cables and (2) physical properties, tensile properties, and chemical analysis for insulation specimens (as appropriate). Section 5.6 provides a summary of the results.

5.1 EPR D lot 1

5.1.1 Cables

Visual Examination

Immediately after the accident simulation, no degradation was evident for the single conductor, multiplex, or multiconductor cables--except for cables A and B. The jackets of cables C and D were intact but the jackets of cables A and B were split longitudinally. At this point in time, no copper conductors were visible for cables A and B. Although no film was evident on the jackets of cables C and D, the jackets of cables A and B were still covered with the white film that was evident after aging. A chemical analysis of this film identified many constituents which are listed in Appendix F.

After completing the IR and AC leakage current tests (including the five minute at 2400 V test), the cables were reexamined. Degradation was only visible for cables A and B. Cable A had a longitudinal split in the jacket for all three wraps; cable B had a longitudinal split in the jacket for one wrap. In order to locate the insulation breakdown of cables A and B, AC voltage was applied to the cables in dry air. The smoke identified insulation faults in all three conductors of cables A and B. Because the insulation had bowed away from the bare conductor, the bare conductor was visible on one wrap of cable A. The cables are shown in Figure 22.

Circumferential Measurements

Within a week after the accident simulation, the circumference of each cable was measured and compared to the original circumference.

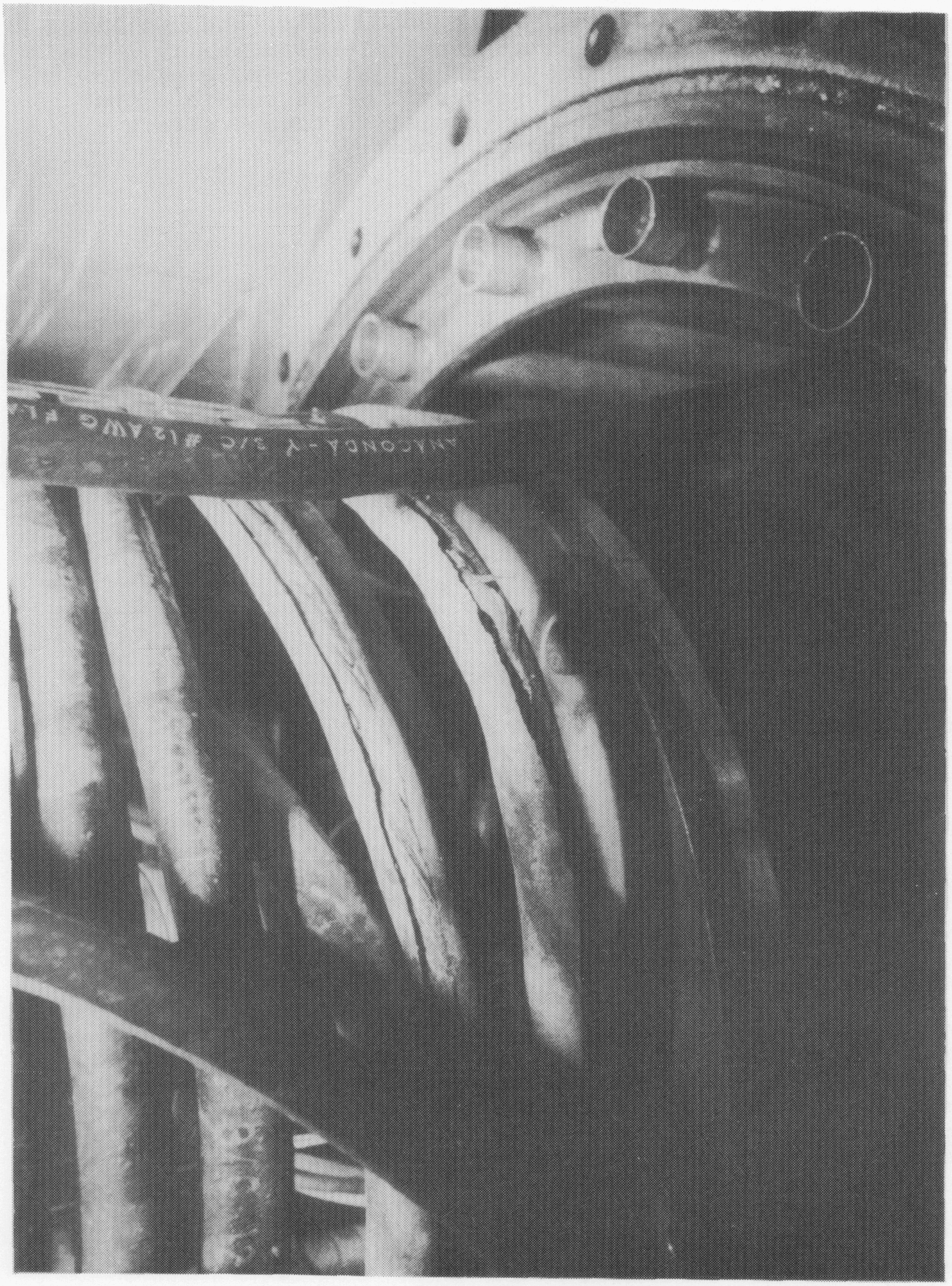


Figure 22. Posttest: Aged EPR D lot 1

As Table 12 shows, the jackets for both cables A and B increased in circumference by approximately 8 percent. However, the jackets were unable to accommodate the swelling of the insulation and the jackets split longitudinally. The final circumference of cables A and B (jacket and gap) had increased by approximately 28 percent. It is possible that the dimensional swelling of the insulation caused stress buildup within the multiconductor geometry.

Table 12

Circumference Measurements For Cables A, B, C, D, G, and H

Cable	Posttest Cable: Average Circumference (cm)		Virgin Cable: Circumference (cm)	Percent Change
A	4.45 ± 0.0	(3.81 ± 0.0)*	3.48	27.7(9.5)*
B	4.47 ± 0.0	(3.76 ± 0.0)*	3.48	28.5(8.0)*
C	4.01 ± 0.08		3.48	15.3
D	3.99 ± 0.10		3.48	14.2
G	3.02 ± 0.03		2.41	25.3
H	1.65 ± 0.03		1.32	24.0

* The numbers in parentheses refer to the jacket only.

Note: The circumference measurement on cables A and B included the jacket and the gap.

The following cables had approximately a 25 percent increase in circumference: aged single conductor (H), aged multiplex (G), and aged multiconductor (A and B). However, the unaged multiconductor cables (C and D) only had a 15 percent increase in circumference.

IR Measurements

The IR measurements for each cable, after one minute at 500 V, are plotted in Figures 23 and 24. The measurements include values taken prior to aging, after aging, throughout the accident exposure, and after the test. Only cables A and B had IR values that were below the instrument range (less than 1.0×10^5 ohms after one minute at 50 V).

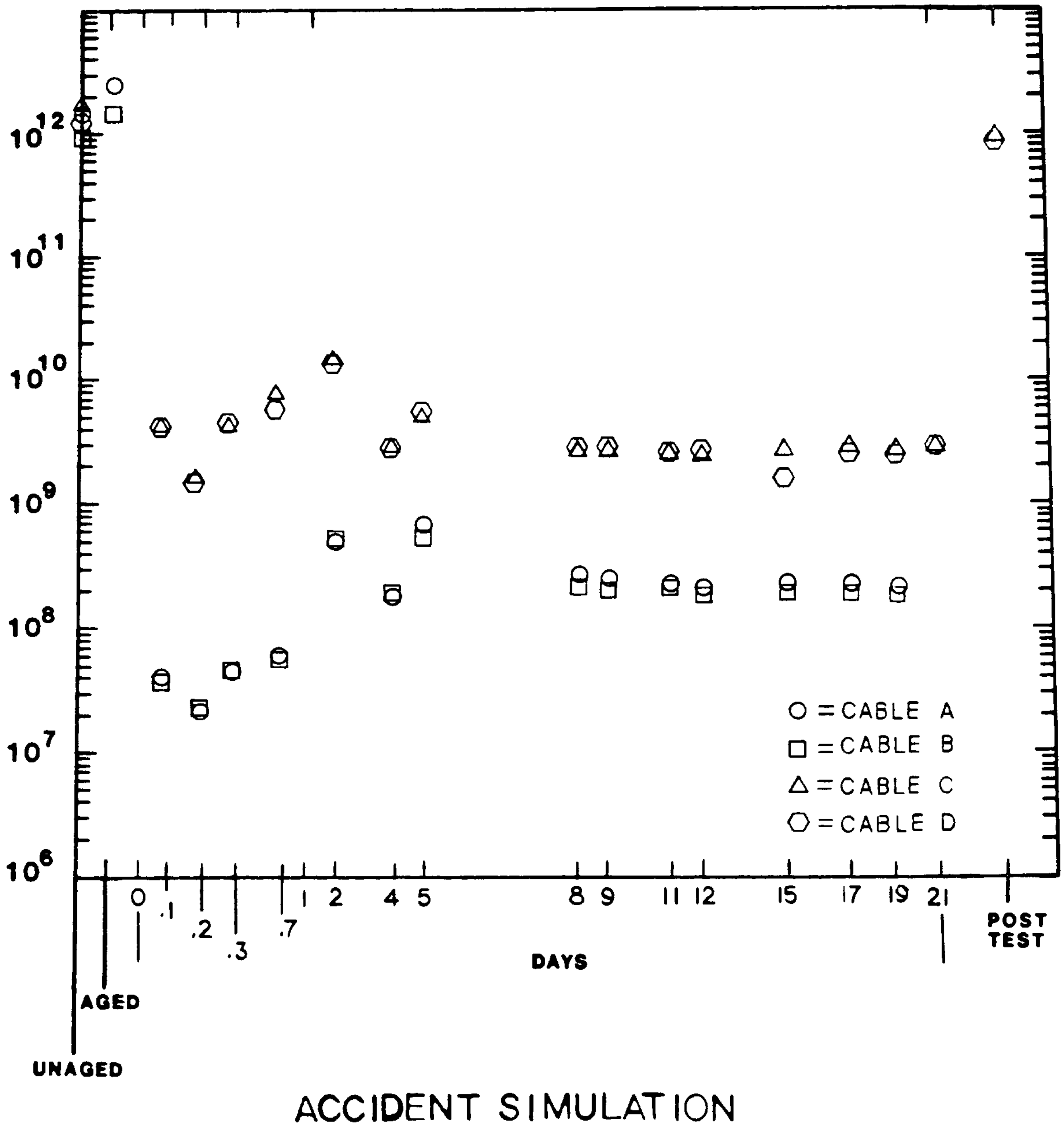


Figure 23. Insulation Resistance Measurements for Cables A, B, C, and D. (Note: at 21 days into the accident and during posttest measurements, the IR values for cables A and B were below 10^6 ohm.)

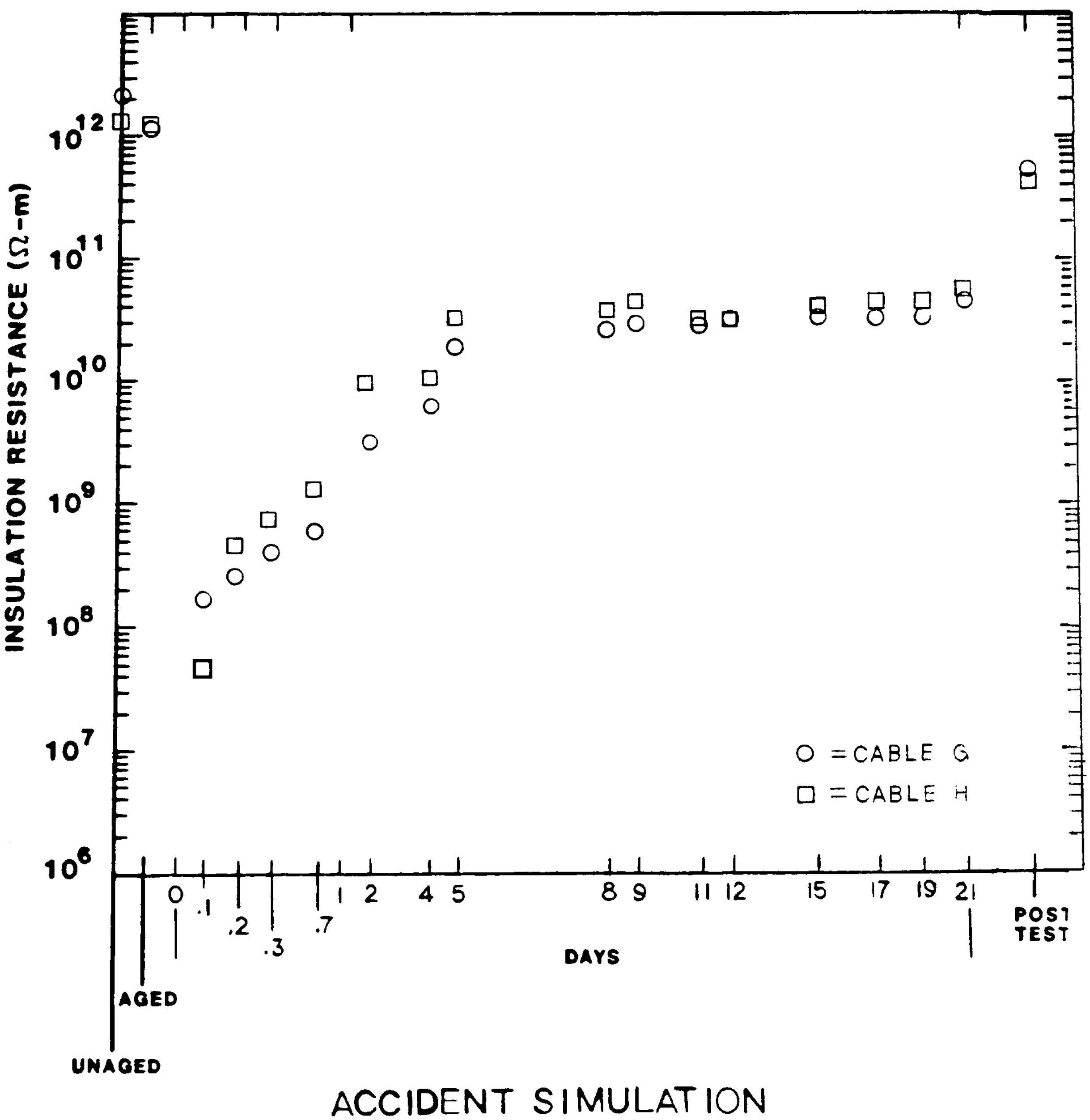


Figure 24. Insulation Resistance Measurements for Cables G and H

AC Leakage Current Measurements

The AC leakage current measurements involved applying voltage to each cable at the following levels and times: 600 V for one minute, 1200 V for one minute, 1800 V for one minute, and 2400 V (80 V/mil) for five minutes. All measurements were made prior to removing the cables from the mandrels rather than following the more severe guidelines in IEEE-383. (IEEE-383 recommends that the cables be straightened and recoiled around a mandrel with a diameter of approximately forty times the overall cable diameter prior to the 80 V/mil withstand test.)

The AC leakage current values, for one conductor to ground, are listed in Table 13. All cables, with the exception of cables A and B, passed each test with less than 5 mA leakage. Cables A and B (aged, multiconductor) had leakage currents which exceeded the capacity of the equipment during the measurement at 1800 V. All AC leakage current values are listed in Appendix D.

Table 13

Posttest AC Leakage Current Measurements for EPR D Lot 1

	Cable* (mA)					
Test Conditions	A	B	C	D	G	H
after 1 minute at 600 V	2.0	2.3	.8	.8	.8	.6
after 1 minute at 1200 V	4.8	4.7	1.7	1.6	1.8	1.6
after 1 minute at 1800 V	>750	>750	2.5	2.7	2.8	2.6
after 5 minutes at 2400 V	-	-	3.4	3.4	4.2	3.9

* White conductor to ground only

Chemical Analysis of Virgin Multiconductor Cable

The analysis, by Huffman Laboratories, is found in Appendix F. As shown in Table 14, jacket and insulation samples of EPR D lot 1 were analyzed for chlorine and bromine content. The jacket consisted of 13.6 percent chlorine and 4.9 percent bromine; the insulation consisted of 8.2 percent chlorine and less than 0.3 percent bromine.

Table 14

Results of the Chemical Analysis for EPR D lot 1

	Jacket (Sample #1)
Cl	13.57 percent
Br	4.86 percent

	Insulation (Sample #2)
Cl	8.20 percent
Br	< 0.30 percent

5.1.2 Insulation Specimens

Table 15 lists the weight increases, dimensional increases, and changes in tensile properties for insulation specimens that were exposed to the accident and the following aging conditions: unaged; aged (by five different methods) to 25 Mrad and an equivalent of 20 years; aged (by five different methods) to 50 Mrad and an equivalent of 40 years; and aged in the HIACA to 40 Mrad and an equivalent of 40 years.

The physical properties and tensile properties did not improve as the accelerated aging time was increased (i.e., dose rate and temperature were lowered). This indicates that in both the superheated-steam and the previous saturated-steam tests, the aging conditions were not inducing artificial degradation.

In addition, graphs of the posttest reduction in sample weight with time are found in Appendix G. The graphs show that all insulation specimens absorbed water during the test. Also a chemical change was identified since the weight of the insulation specimens, after the water desorbed, was greater than the virgin weight.

5.2 EPR D lot 2

5.2.1 Cables

Visual Examination

No cable degradation was observed for the single or multiconductor cables. The jackets of cables E and F were

Table 15

Measurements Taken After the Accident for EPR D Lot 1

A G I N G   C O N D I T I O N S

		25 Mrad: Batches					50 Mrad: Batches					40 Mrad
	Unaged	1	2	3	4	5	1	2	3	4	5	(HIACA aged)
% weight increase	29.4	107.4	45.5	87.7	114.3	95.3	88.9	92.7	103.9	109.2	145.1	118.3
% length increase	5.6	24.4	8.5	19.4	23.3	19.4	20.6	21.0	22.7	-	27.3	25.0
% diameter increase	8.3	31.4	14.7	27.6	31.4	26.9	27.6	25.6	29.5	33.3	38.5	34.0
e/e_o	.13	.12	.18	.17	.11	.19	.05	.05	.10	.04	.09	.05
T/T_o*	.69	.52	.77	.67	.46	.77	.42	.44	.54	.39	.48	.34

* normalized to virgin cross-sectional area

Measurements: weight -- measured 9/16/85
length -- measured 9/23/85
diameter -- measured 9/23/85
e -- measured 1/3/86
T -- measured 1/3/86

intact and were still covered with the white film that was evident after aging. A chemical analysis of this film identified many constituents which are listed in Appendix F.

After completing the IR and AC leakage current tests (including the five minute at 2400 V test), the cables were reexamined and no cable degradation was observed. The cables are shown in Figure 21.

Circumferential Measurements

Within a week after the accident simulation, the circumference of each cable was measured and compared to the original circumference.

As Table 16 shows, the circumference for the aged multiconductor cables E and F increased by 8 percent; while, the aged single conductor cable (I) increased in circumference by 25 percent. Unlike the EPR D lot 1 case, the jacket for EPR D lot 2 accommodated the swelling without splitting.

Table 16

Circumference Measurements For Cables E, F, and I

Cable	Posttest Cable: Average Circumference (cm)	Virgin Cable: Circumference (cm)	Percent Change
E	3.81 ± 0.03	3.53	7.6
F	3.86 ± 0.03	3.53	9.0
I	1.60 ± 0.03	1.27	25.0

IR Measurements

The IR measurements for each cable, after one minute at 500 V, are plotted in Figures 25 and 26. The measurements include values taken prior to aging, after aging, throughout the accident exposure, and after the test. All cables had acceptable IR values.

AC Leakage Current Measurements

The AC leakage current measurements involved applying voltage to each cable at the following levels and times: 600 V for one minute, 1200 V for one minute, 1800 V for one minute, and 2400 V (80 V/mil) for five minutes. All measurements were made prior to removing the cables from the mandrels rather than following the more severe guidelines in

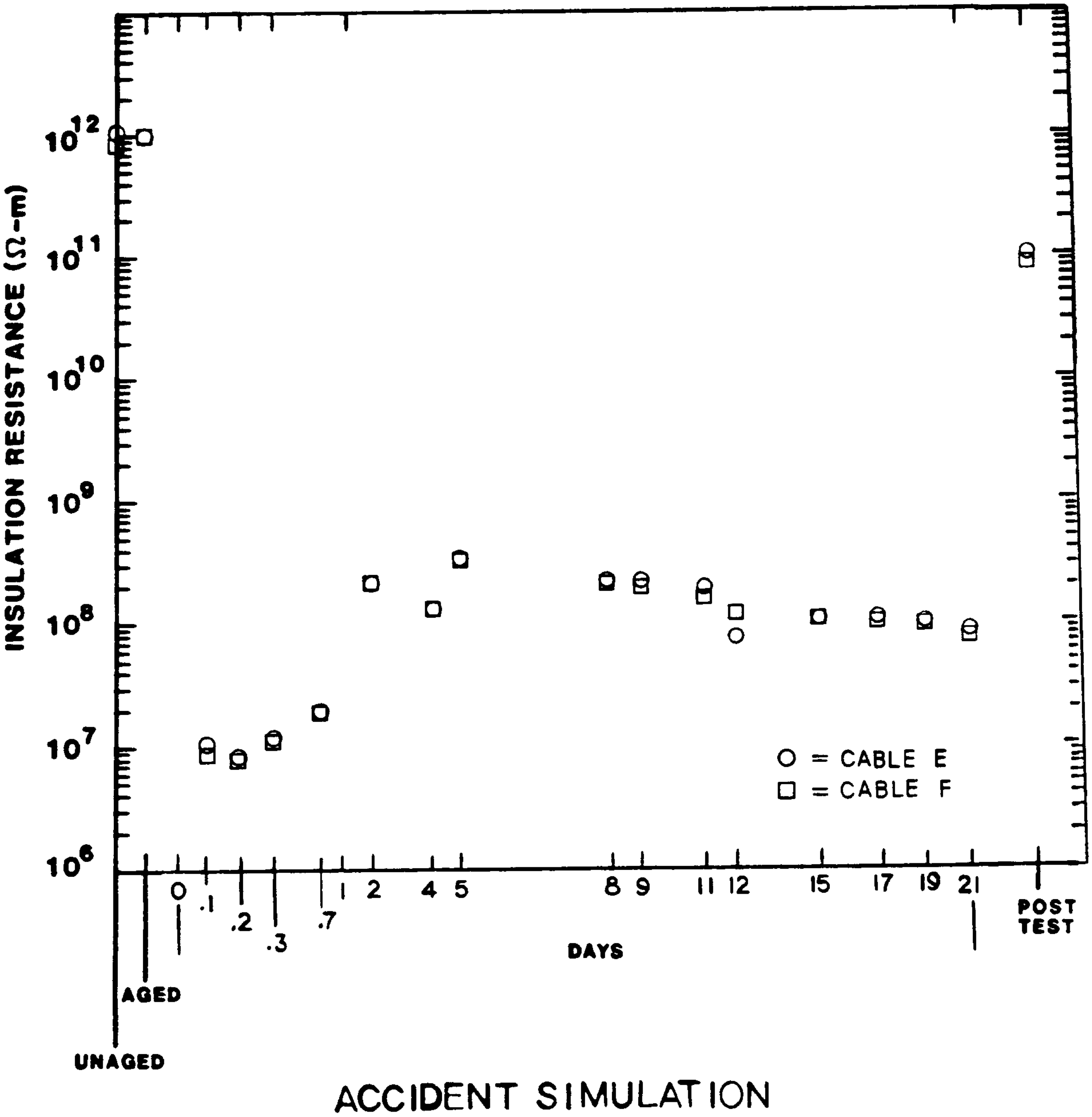


Figure 25. Insulation Resistance Measurements for Cables E and F

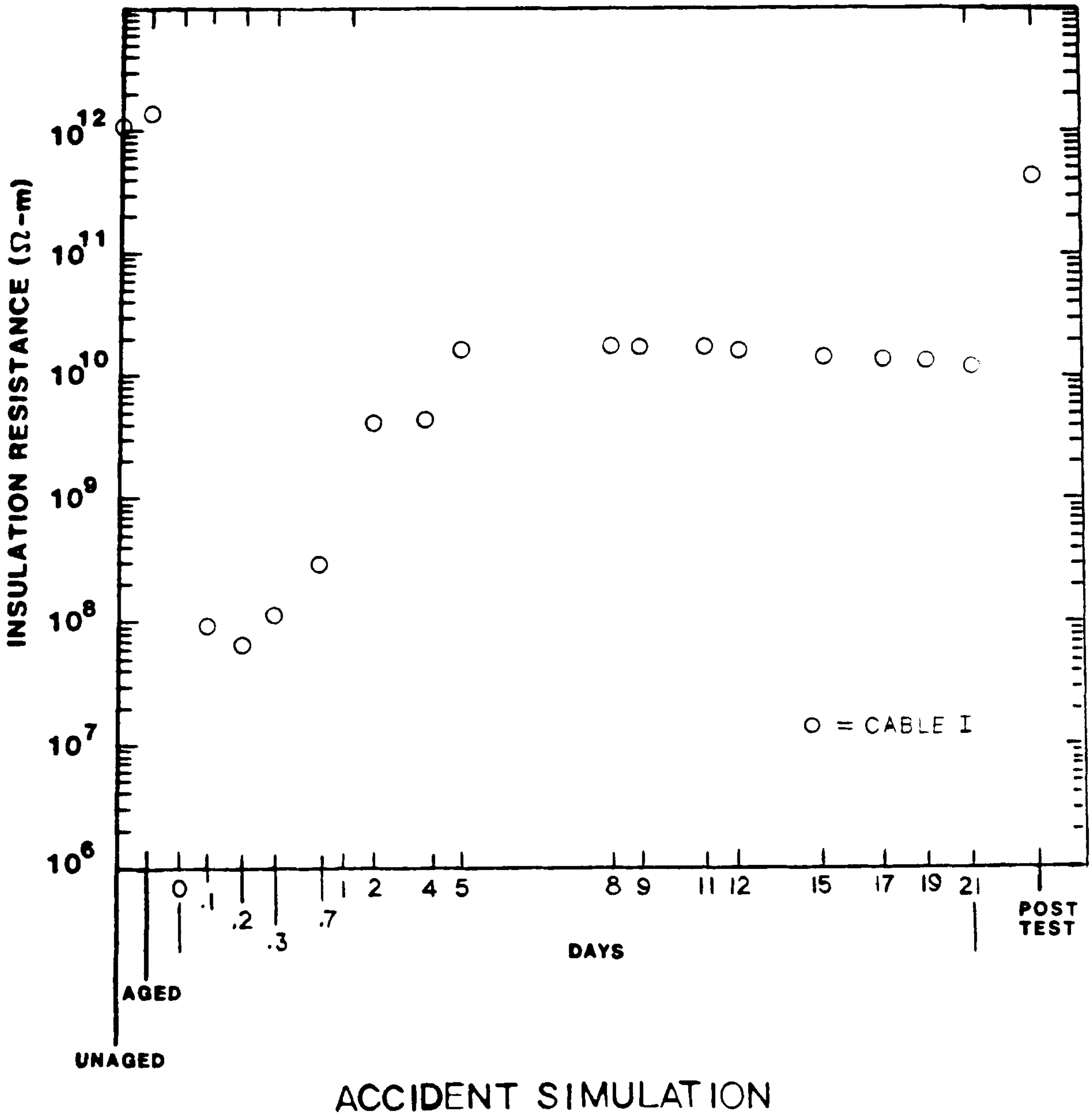


Figure 26. Insulation Resistance Measurements for Cable I

IEEE-383. (IEEE-383 recommends that the cables be straightened and recoiled around a mandrel with a diameter of approximately forty times the overall cable diameter prior to the 80 V/mil withstand test.)

The AC leakage current values, for one conductor to ground, are listed in Table 17. All cables passed each test with less than 5 mA leakage. All AC leakage current values are listed in Appendix D.

Table 17

Posttest AC Leakage Current Measurements for EPR D Lot 2

Test Conditions	Cables* (mA) E	F	I
after 1 minute at 600 V	1.1	1.0	0.7
after 1 minute at 1200 V	2.3	2.1	1.4
after 1 minute at 1800 V	3.7	3.2	2.1
after 5 minutes at 2400 V	4.9	4.3	2.8

* White conductor to ground only

Chemical Analysis of Virgin Multiconductor Cable

The analysis, by Huffman Laboratories, is found in Appendix F. As shown in Table 18, the jacket and insulation samples of EPR D lot 2 were analyzed for chlorine and bromine content. The jacket consisted of 13.5 percent chlorine and 5.0 percent bromine; the insulation consisted of less than 0.2 percent chlorine and 11.4 percent bromine. The jackets of EPR D lot 1 and lot 2 are similar, but the insulation is different. (EPR D lot 1 has chlorine but minimal bromine; while, EPR D lot 2 has bromine and minimal chlorine.)

5.2.2 Insulation Specimens

Table 19 lists the weight increases, dimensional increases, and changes in tensile properties for insulation specimens that were exposed to the accident and the following aging conditions: unaged and aged in the HIACA to 40 Mrad and an equivalent of 40 years.

The physical properties and tensile properties show similar behavior between the unaged insulation specimens of EPR D lot 1 and EPR D lot 2. However for the HIACA aged

Table 18

Results of the Chemical Analysis for EPR D Lot 2

	Jacket (Sample #3)	
Cl	13.48	percent
Br	4.97	percent
	Insulation (Sample #4)	
Cl	< 0.20	percent
Br	11.36	percent

Table 19

Measurements Taken After the Accident for EPR D Lot 2

AGING CONDITIONS

	Unaged	40 Mrad (HIACA Aged)
% weight increase	22.7	35.5
% length increase	7.9	8.5
% diameter increase	7.7	11.5
e/e_o	0.19	0.15
T/T_o*	0.86	0.88

* normalized to virgin cross-sectional area

Measurements: weight -- measured 9/16/85
length -- measured 9/23/85
diameter -- measured 9/23/85
e -- measured 1/3/86
T -- measured 1/3/86

insulation specimens, EPR D lot 1 had greater moisture absorption (factor of 3) and lower tensile properties (factor of 3) than EPR D lot 2.

In addition, graphs of the posttest reduction in sample weight with time are found in Appendix G. The graphs show that all insulation specimens absorbed water during the test. Also a chemical change was identified since the weight of the insulation specimens, after the water desorbed, was greater than the virgin weight.

5.3 EPR F: Insulation Specimens

Table 20 lists the weight increases, dimensional increases, and changes in tensile properties for insulation specimens that were exposed to the accident and the following aging conditions: unaged; aged (by five different methods) to 25 Mrad and an equivalent of 20 years; and aged (by five different methods) to 50 Mrad and an equivalent of 40 years.

The physical properties and tensile properties did not improve as the accelerated aging time was increased (i.e., dose rate and temperature were lowered). This indicates that in both the superheated-steam and the previous saturated-steam tests, the aging conditions were not inducing artificial degradation.

In addition, graphs of the posttest reduction in sample weight with time are found in Appendix G. The graphs show that all insulation specimens absorbed water during the test. Also a chemical change was identified since the weight of the insulation specimens, after the water desorbed, was greater than the virgin weight.

<u>Chemical Analysis of Virgin Insulation</u>

The analysis, by Huffman Laboratories, is found in Appendix F. As shown in Table 21, the insulation sample of EPR F was analyzed for chlorine and bromine content. The insulation consisted of 10.3 percent chlorine and less than 0.3 percent bromine.

5.4 EPR H

5.4.1 <u>Cables</u>

<u>Visual Examination</u>

Immediately after the accident simulation and after completing the IR and AC leakage current tests (including

Table 20

Measurements Taken After the Accident for EPR F

		AGING CONDITIONS									
		25 Mrad: Batches					50 Mrad: Batches				
	Unaged	1	2	3	4	5	1	2	3	4	5
% weight increase	19.0	60.0	44.9	57.1	70.3	62.7	73.8	90.8	97.5	116.5	110.9
% length increase	2.1	13.0	8.4	11.8	18.7	12.4	16.5	19.3	23.3	28.4	24.4
% diameter increase	7.3	19.9	16.7	19.9	21.5	21.5	24.2	29.6	31.2	27.4	34.4
e/e_o	.12	.11	.11	.13	.10	.10	.05	.08	.04	.03	.03
T/T_o*	.67	.60	.66	.71	.59	.54	.40	.47	.33	.32	.30

* normalized to virgin cross-sectional area

Measurements: weight -- measured 9/16/85
length -- measured 9/23/85
diameter -- measured 9/23/85
e -- measured 1/21/86
T -- measured 1/21/86

Table 21

Results of the Chemical Analysis for EPR F

Insulation (Sample #7)

Cl	10.27 percent
Br	< 0.30 percent

the five minute at 2400 V test), the cables were examined. No cable degradation was observed; however, there was visible swelling of the jacket for each multiconductor cable (J, K, L, and M).

Circumferential Measurements

Within a week after the accident simulation, the circumference of each cable was measured and compared to the original circumference.

As Table 22 shows, the circumference for the following cables increased by about 25 percent: aged single conductor (O) and aged multiconductor (J and K) cables. The unaged multiconductor cables (L and M) increased in circumference by 17 percent; the aged multiplex cable (N) increased by 6 percent.

Table 22

Circumference Measurements For Cables J, K, L, M, N, and O

Cable	Posttest Cable: Average Circumference (cm)	Virgin Cable: Circumference (cm)	Percent Change
J	4.60 ± 0.08	3.73	23.1
K	4.60 ± 0.03	3.73	23.1
L	4.37 ± 0.03	3.73	17.0
M	4.39 ± 0.05	3.73	17.7
N	2.95 ± 0.0	2.79	5.5
O	1.73 ± 0.05	1.37	25.0

IR Measurements

The IR measurements for each cable, after one minute at 500 V, are plotted in Figures 27 and 28. The measurements include values taken prior to aging, after aging, throughout the accident exposure, and after the test. All cables had acceptable IR values.

AC Leakage Current Measurements

The AC leakage current measurements involved applying voltage to each cable at the following levels and times: 600 V for one minute, 1200 V for one minute, 1800 V for one minute, and 2400 V (80 V/mil) for five minutes. All measurements were made prior to removing the cables from the mandrels rather than following the more severe guidelines in IEEE-383. (IEEE-383 recommends that the cables be straightened and recoiled around a mandrel with a diameter of approximately forty times the overall cable diameter prior to the 80 V/mil withstand test.)

The AC leakage current values, for one conductor to ground, are listed in Table 23. All cables passed each test with less than 5 mA leakage. All AC leakage current values are listed in Appendix D.

Chemical Analysis of Virgin Multiconductor Cable

The analysis, by Huffman Laboratories, is found in Appendix F. As shown in Table 24, the jacket and insulation samples of EPR H were analyzed for chlorine and bromine content. The jacket consisted of 11.1 percent chlorine and less than 0.3 percent bromine; the insulation consisted of 9.6 percent chlorine and less than 0.3 percent bromine. (The insulation of EPR F and EPR H is similar.)

5.4.2 Insulation Specimens

Table 25 lists the weight increases, dimensional increases, and changes in tensile properties for insulation specimens that were exposed to the accident and the following aging conditions: unaged and aged in the HIACA to 40 Mrad and an equivalent of 40 years.

When comparing unaged EPR F to unaged EPR H or aged EPR F (Batch 2, 50 Mrad) to aged EPR H insulation specimens, the physical properties and tensile properties differed by approximately a factor of 2 or less.

In addition, graphs of the posttest reduction in sample weight with time are found in Appendix G. The graphs show that all insulation specimens absorbed water during the

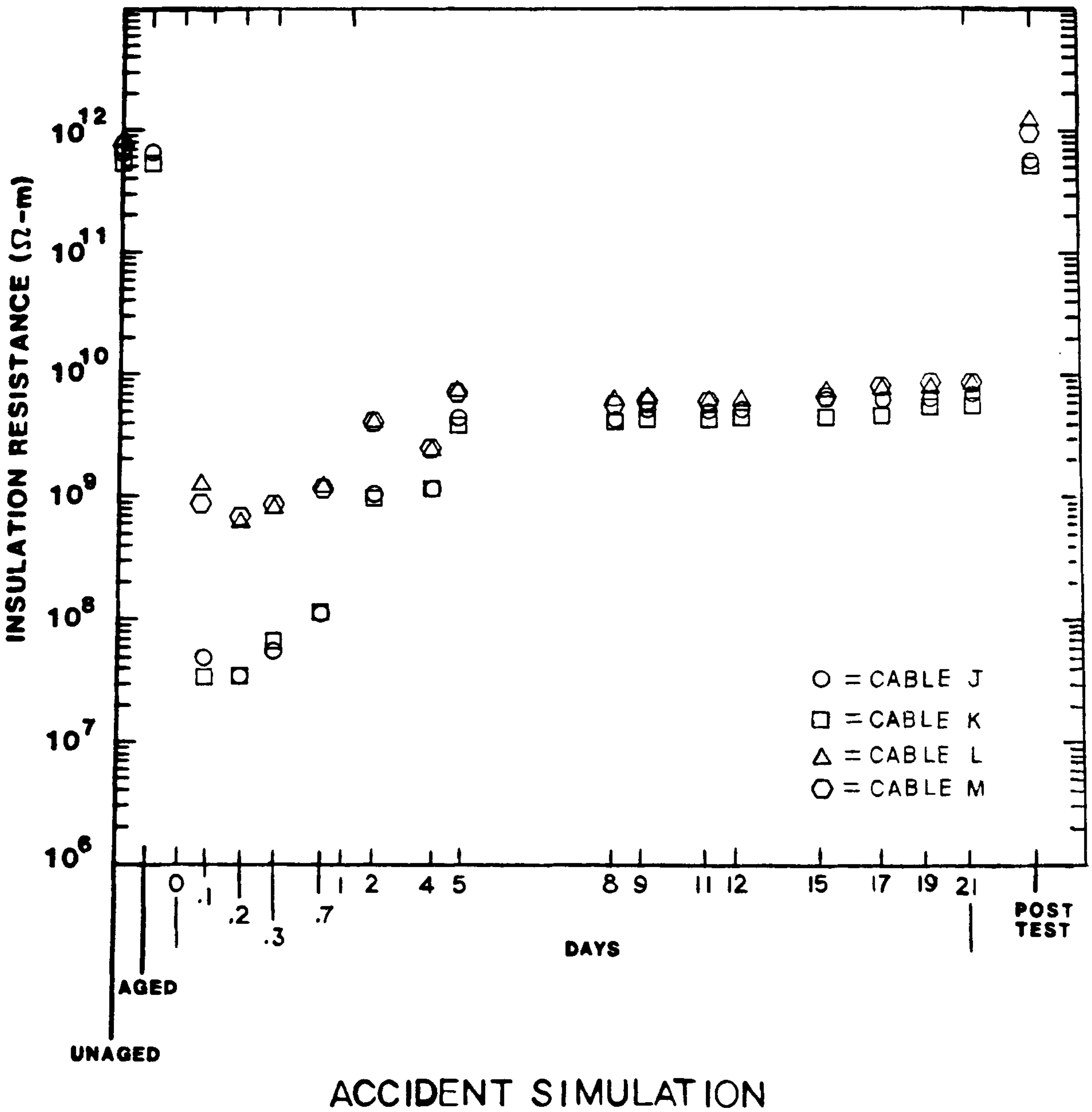


Figure 27. Insulation Resistance Measurements for Cables J, K, L, and M

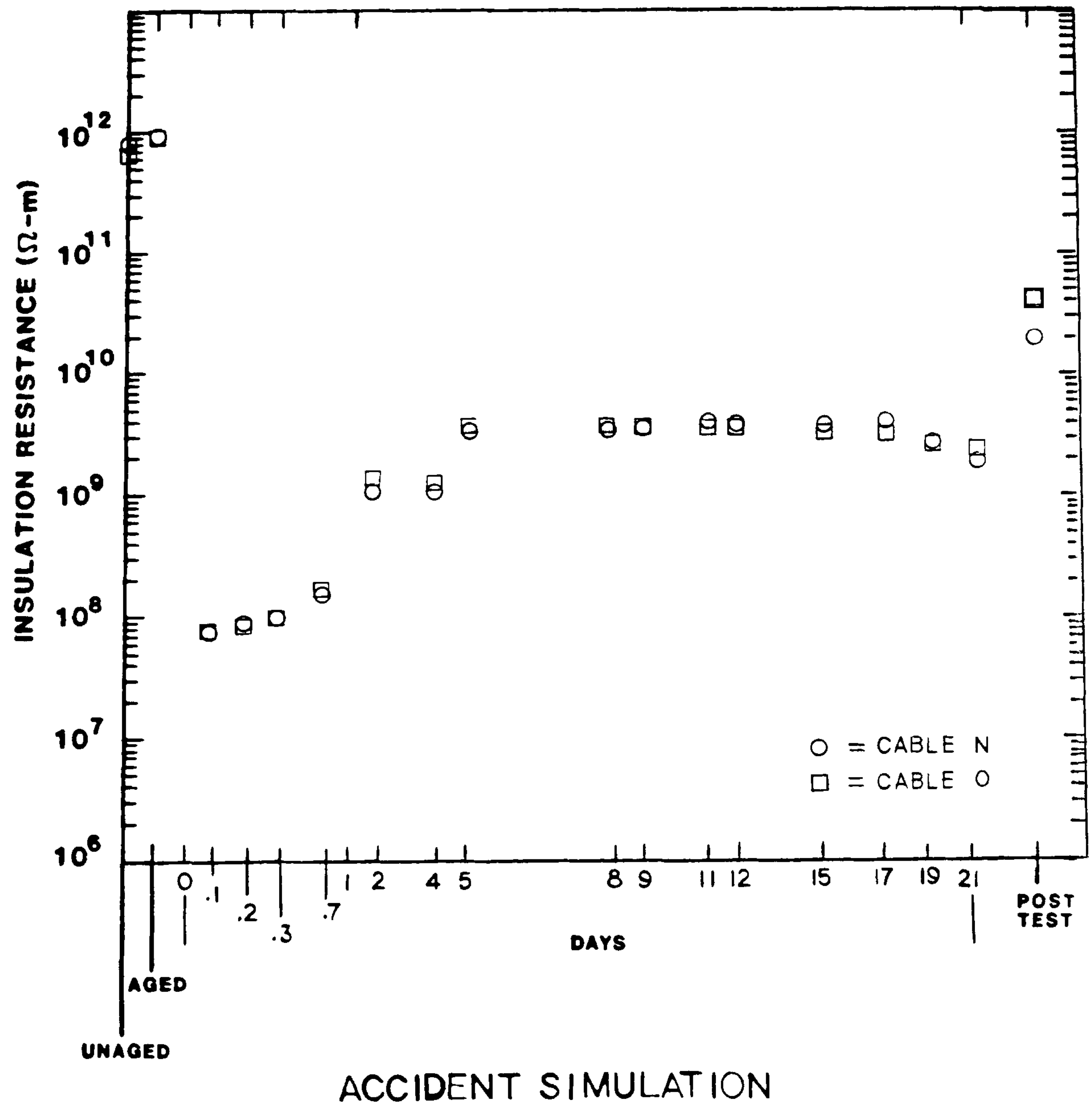


Figure 28. Insulation Resistance Measurements for Cables N and O

Table 23

Posttest AC Leakage Current Measurements for EPR H

Test Conditions	Cable* (mA) J	K	L	M	N	O
after 1 minute at 600 V	0.9	0.8	0.8	0.8	1.0	0.6
after 1 minute at 1200 V	1.7	1.9	1.7	1.6	1.8	1.4
after 1 minute at 1800 V	2.7	2.5	2.5	2.4	3.0	2.2
after 5 minutes at 2400 V	3.5	3.5	3.3	3.2	4.2	3.4

* White conductor to ground only

Table 24

Results of the Chemical Analysis for EPR H

Jacket (Sample #5)

Cl	11.05 percent
Br	< 0.30 percent

Insulation (Sample #6)

Cl	9.61 percent
Br	< 0.30 percent

Table 25

Measurements Taken After the Accident for EPR H

AGING CONDITIONS

	Unaged	40 Mrad (HIACA Aged)
% weight increase	31.0	85.2
% length increase	5.0	19.3
% diameter increase	11.3	26.9
e/e_o	0.24	0.22
T/T_o*	0.81	0.79

* normalized to virgin cross-sectional area

Measurements:	weight --	measured 9/16/85
	length --	measured 9/23/85
	diameter --	measured 9/23/85
	e --	measured 1/3/86
	T --	measured 1/3/86

test. Also a chemical change was identified since the weight of the insulation specimens, after the moisture desorbed, was greater than the virgin weight.

5.5 EPR 1483: Insulation Specimens

Table 26 lists the weight increases, dimensional increases, and changes in tensile properties for insulation specimens that were exposed to the accident simulation and the following aging conditions: unaged; aged to 25 Mrad and an equivalent of 20 years; and aged to 50 Mrad and an equivalent of 40 years.

By comparing the physical properties and tensile properties of Batch 1 (chlorine fire retardant) to Batch 3 (bromine fire retardant), the choice of halogen fire retardant appears to make little difference. However when comparing Batches 1 and 3 (batches with a fire retardant) to Batch 2 (no fire retardant), Batch 2 absorbed less moisture and had better tensile properties.

When comparing Batches 1 and 4 (with different surface treated clays but the same chlorine fire retardant), Batch 1 (Translink 37 surface treated clay) and Batch 4 (Burgess KE

Table 26

Measurements Taken After the Accident - EPR 1483

EPR 1483

	Unaged: Batches*						25 Mrad: Batches*						50 Mrad: Batches*					
	1	2	3	4	5	6	1	2	3	4	5	6	1	2	3	4	5	6
% weight increase	15.0	3.4	15.6	44.9	3.5	-38.6	19.9	2.1	18.3	36.9	-.9	-19.9	30.4	3.2	22.4	11.8	6.5	-8.3
% length increase	4.9	0.0	6.4	4.7	1.9	7.0	8.2	-.6	7.0	8.1	4.1	17.4	12.9	0.0	9.3	14.0	5.8	24.4
% thickness increase	11.9	11.8	8.5	3.6	10.4	7.3	4.8	3.5	9.5	14.3	5.2	28.0	7.1	-2.8	11.0	22.6	8.6	32.9
% width increase	2.7	-1.6	6.0	4.8	-3.9	3.4	2.7	-3.2	2.4	4.0	-2.3	6.8	3.1	4.7	1.2	6.0	0.0	11.3
T/T_o	.468	.922	.570	.491	.413	.300	.401	.895	.552	.453	.413	.280	.388	.859	.519	.309	.431	.266
e/e_o	.134	.341	.168	.160	.272	.069	.099	.381	.150	.122	.223	.050	.095	.352	.156	.077	.203	.040

* Description of each batch in Table 2.

Measurements: weight -- measured 9/16/85
length -- measured 9/23/85
thickness -- measured 9/23/85
width -- measured 9/23/85
T -- measured 9/24-25/85
e -- measured 9/24-25/85

surface treated clay) had similar tensile properties. However as the total aging increased, the posttest weight of Batch 1 increased while the weight of Batch 4 decreased.

The posttest weight for Batch 5 (nonsurface treated clay with a chlorine fire retardant) indicated a loss of ingredients and other chemical changes as aging increased.

For Batch 6 (no vinyl silane bonding but with a surface treated clay and a chlorine fire retardant), at each aging level, some ingredients have been lost and chemical changes have occurred. Although the posttest weight remained less than the virgin sample weight in all cases, the posttest weight did increase as the total aging increased.

In addition, graphs of the posttest reduction in sample weight with time are found in Appendix G. The graphs show that the weight of the insulation specimens remained relatively constant--only a minimal amount of moisture was desorbing. For Batches 1, 2, 3, and 4 (at each aging level) and Batch 5 (unaged samples), the posttest weight of the insulation specimens was greater than the virgin weight. Therefore, some chemical change occurred. However, for Batch 5 (aged samples) and Batch 6 (at each aging level), the posttest weight of the insulation specimens was less than the virgin weight. Therefore some ingredients have been lost and other chemical changes have occurred. These results agree with the results from the measurements of physical and tensile properties.

5.6 Summary of Results

5.6.1 Cables

Aged single conductors, aged multiplex, and unaged multiconductor EPR D lot 1 cables survived the test--including the five minute 80 V/mil withstand test. However, the aged multiconductors of EPR D lot 1 failed to maintain high IR values 19 to 21 days into the accident simulation. Furthermore, for these two aged multiconductor cables, the jackets were split at the conclusion of the accident simulation and the cables failed the 1 minute at 1800 Vac test (which is less severe than the five minute 80 V/mil withstand test).

All EPR D lot 2 cables (aged single and aged multiconductors) survived the test--including the five minute 80 V/mil withstand test.

All (aged single conductor; aged multiplex; and aged and unaged multiconductor) EPR H cables survived the test--including the five minute 80 V/mil withstand test.

5.6.2 Insulation Specimens

For the insulation specimens that were exposed to five different aging conditions (EPR D lot 1 and EPR F), the physical properties and tensile properties, measured after the accident simulation, did not improve as the accelerated aging time was increased (i.e., dose rate and temperature were lowered).

Insulation specimens (EPR D lot 1, EPR D lot 2, EPR F, and EPR H) absorbed moisture during the test and desorbed moisture after the test.

A chemical change was evident for EPR D lot 1, EPR D lot 2, EPR F, and EPR H, since the posttest weight of the insulation specimens (after the moisture desorbed) was greater than the virgin weight.

The unaged EPR D lot 1 and EPR D lot 2 insulation specimens show similar physical and tensile properties. For the aged insulation specimens, EPR D lot 1 had more moisture and lower tensile properties (by a factor of 3) than EPR D lot 2.

Unaged and aged (Batch 2, 50 Mrad) EPR F insulation specimens had physical and tensile properties within a factor of 2 or less of the corresponding EPR H insulation specimens.

For EPR 1483, the batch without the fire retardant absorbed less moisture and had better tensile properties than batches with either the chlorine or bromine fire retardant.

For the EPR 1483 formulations with a chlorine fire retardant but with different surface treated clays, the formulations showed similar tensile properties but different moisture absorption properties as aging increased.

From examining the posttest reduction in weight:

- Chemical changes occurred by the end of the test for EPR 1483 Batches 1, 2, 3, and 4.

- The nonsurface treated clay formulation (EPR 1483 Batch 5) and the formulation which eliminated the vinyl silane (EPR 1483 Batch 6) led to a loss of ingredients and other chemical changes.

Unlike the EPR D lot 1, EPR D lot 2, EPR F, and EPR H insulation specimens, the posttest weight of the EPR 1483 (Batches 1 through 6) insulation specimens remained relatively constant--only a minimal amount of moisture was desorbed.

6. CONCLUSIONS OF THE SUPERHEATED-STEAM TEST

The questions addressed by each subtest, summary of pertinent results, and conclusions are discussed below.

Subtest 1

The purpose of Subtest 1 was to answer two questions: (1) Will EPR D lot 1 multiconductor cables experience substantial electrical degradation if superheated-steam rather than saturated-steam conditions are used at the start of the LOCA profile? and (2) Do other EPR cable products show different electrical results between single and multiconductor configurations? In addition, Subtest 1 provided a comparison between different cable lots and provided information on jacket-insulation interaction effects by including three configurations of cables.

The results of Subtest 1 have shown that aged EPR D lot 1 multiconductor cables (but not aged single conductor, aged multiplex, or unaged multiconductor cables) experienced substantial electrical degradation when superheated-steam conditions were used at the start of the LOCA profile. Electrical degradation occurred between 19 to 21 days into the accident simulation--slightly later than the saturated-steam test.

However, EPR D lot 2 and EPR H did not show different electrical results between single and multiconductor configurations. Therefore, the following conclusions were drawn:

1. Since the same results occurred using either superheated-steam or saturated-steam at the start of the accident simulation, it does not appear that saturated-steam conditions forced moisture into the cable causing the cable to fail prematurely. (Superheated-steam only delayed the electrical degradation of the cables slightly.)

2. Since only one product (aged multiconductor EPR D lot 1 cable) had low IR values and large leakage currents, the differences between the electrical degradation of single and multiconductor cables do not appear to be generic to all cables. However, because single conductors and multiconductors did behave differently for the aged EPR D lot 1 cables, the current equipment qualification practice of using single conductors to qualify multiconductors may not be a conservative approach for all cables.

3. Since cable electrical degradation was not observed until several days after the start of the accident exposure, safety systems that are required only at the start of an accident may not be impacted by this degradation process.

4. EPR D lot 1 was certified to LOCA requirements, but failed to maintain high insulation resistance values throughout the test. EPR D lot 2, although not certified, passed the test. From a chlorine and bromine analysis, the insulation was found to be different for each lot. However, since the physical and tensile properties were similar between batches of EPR-1483 (from Subtest 3) with a chlorine or a bromine fire retardant, other formulation differences and the processing between lots 1 and 2 may be different.

Subtest 2

The purpose of Subtest 2 was to determine if the aging technique, used during the aging portion of the saturated-steam test, influenced moisture absorption in the insulation and thereby induced artificial degradation. From the results of testing EPR D lot 1 and EPR F insulation specimens at five different aging conditions, the following conclusion was drawn:

1. The aging dose rates and temperatures in the superheated-steam and saturated-steam tests were not inducing artificial degradation because the physical and tensile properties (measured after the accident simulation) did not improve as the accelerated aging time was increased.

Subtest 3

The purpose of Subtest 3 was (1) to identify constituents which cause moisture absorption and dimensional swelling in the insulation and (2) to help establish the applicability of the test results to other cable products. From the results of EPR 1483 testing, the following conclusions can be drawn:

1. The presence of a fire retardant influenced the moisture absorption and tensile properties of a material. (EPR-1483 insulation specimens without a fire retardant absorbed less moisture and had better tensile properties than those with a fire retardant.)

2. All the EPR-1483 insulation specimens showed a chemical change after the accident simulation; however, removing the surface treatment of the clay or the vinyl silane bonding seemed to cause a loss of ingredients in addition to other chemical changes.

7. COMPARISON BETWEEN THE RESULTS OF THE SUPERHEATED-STEAM TEST AND THE PREVIOUS SATURATED-STEAM TESTS

EPR D lot 1, single conductor and multiconductor cables were used in the superheated-steam and saturated-steam tests. The cables exhibited the same behavior in these tests. These results are described below.

Single Conductor Cables

For the single conductor cables, both tests showed high IR values and low leakage currents.

Multiconductor Cables

Both tests showed the following results for the multiconductor cable:

- The IR values followed the same pattern throughout both tests with the following exception: in the superheated-steam test the IR readings were below the instrument range at 19-21 days into the accident; whereas, in the saturated-steam tests the readings for three different samples of EPR D lot 1 multiconductor cable were below the instrument range at approximately 8, 12, and 18 days into the accident.

- The circumference of the jacket increased during the test, although the jacket increase was not large enough to contain the bundle of conductors.

- The jacket had a longitudinal split.

- The exposed gap in the jacket was approximately .6 cm wide.

- Bare conductors were visible.

- The cables had large leakage currents after one minute at the following voltages:

saturated-steam tests		superheated-steam tests	
600 V	180 - 750 mA	600 V	2 mA
		1200 V	5 mA
		1800 V	750 mA

8. CONCLUSIONS FROM BOTH THE SUPERHEATED-STEAM TEST AND THE SATURATED-STEAM TESTS

From the superheated-steam and the saturated-steam tests, the following general conclusions were drawn.

1. Since a multiconductor jacket provides additional protection to the insulation, current equipment qualification practices use single conductor qualification tests to qualify multiconductor cables. However, both the saturated-steam and the superheated-steam tests indicate that results from single conductor cable tests may not be conservative when trying to qualify multiconductor cables.

2. Since only one product (aged multiconductor EPR D lot 1 cable) had low IR values and large leakage currents, the differences between the electrical degradation of single and multiconductor cables do not appear to be generic to all cables.

3. Since cable electrical degradation was not observed until several days after the start of the accident exposure, safety systems that are required only at the start of an accident may not be impacted by this degradation process.

4. The aging dose rates and temperatures in the superheated-steam and saturated-steam tests were not inducing artificial degradation because the physical and tensile properties (measured after the accident simulation) did not improve as the accelerated aging time was increased.

5. The same results occurred using either superheated-steam or saturated-steam at the start of the accident simulation. Therefore, it does not appear that saturated-steam conditions forced moisture into the cable causing the cable to fail prematurely. (Superheated-steam had little effect other than slightly delaying the time to failure.)

6. It was suggested, in the saturated-steam test, that the single conductor showed no electrical degradation due to the absence of jacket-insulation interaction effects and less severe bending (no helical bend component). Because the multiplex cable in the superheated-steam test had no electrical degradation, the primary cause of multiconductor failure is due to the jacket-insulation interaction effects.

9. REFERENCES

1. L. D. Bustard, The Effect of LOCA Simulation Procedures on Ethylene Propylene Rubber's Mechanical and Electrical Properties, NUREG/CR-3538, SAND83-1258, Sandia National Laboratories, Albuquerque, New Mexico, October 1983.

2. U. I. Vaidya, "Flame Retarded EPDM Integral Insulation Jacket Compositions With Excellent Heat Resistant and Electrical Stability," presented at ACS Rubber Division Meeting, October 12, 1978, Boston, MA.

3. W. H. Buckalew, F. V. Thome, Radiation Capabilities of the Sandia High Intensity Adjustable Cobalt Array, NUREG/CR-1682, SAND81-2655, Sandia National Laboratories, Albuquerque, New Mexico, March 1982.

Appendix A

EPR 1483 Formulation

AKRON RUBBER DEVELOPMENT LABORATORY, INC.
300 KENMORE BOULEVARD
AKRON, OHIO 44301
(216) 434-6664

February 4, 1986

Ms. Pauline Bennett
Sandia National Laboratories, Inc.
Division 6445, Bldg. 823, Room 3026
1515 Eubank Blvd.
Albuquerque, New Mexico 87133

Dear Ms. Bennett,

The following is the correct formulation used on your project in December of 1984.

Nordel 2722	90.00
DYNH No. 1	20.0
Zinc Oxide	5.00
Paraffin Wax	5.00
Zetax	2.00
AMinox	1.00
Silane A 172	1.00
SRF N774	2.00
Litharge	5.00
Di Cup R	5.00
Dechlorane 25	33.00
Antiomony Trioxide	12.00
Whitex Clay	60.00
Total	241.00

If I can be of any further assistance please do not hesitate in contacting me.

Sincerely,

Robert May
AKRON RUBBER DEVELOPMENT LABORATORY, INC.

AKRON RUBBER DEVELOPMENT LABORATORY, INC.
300 KENMORE BOULEVARD
AKRON, OHIO 44301
(216) 434-6664

March 20, 1985

Ms. Pauline Bennett
Sandia National Laboratories, Inc.
Division 6445, Bldg. 823, Room 3026
1515 Eubank Boulevard
Albuquerque, New Mexico 87133

Dear Ms. Bennett,

Please find below the proper formula for compound No.5. Also compounds NO.1, No. 3, No. 4, No. 5 and No. 6 should read antimony trioxide, not antimony oxide.

Nordel 2722	90.00
DYNH No. 1	20.00
Zinc Oxide	5.00
Paraffin Wax	5.00
Zetax	2.00
Aminox	1.00
Silane A - 172	1.00
SRF N 774	2.00
Litharge	5.00
Di Cup R	5.00
Dechlorane - 25	33.00
Antiomony Trioxide	12.00
White Clay	60.00
	241.00

If I can be of any further assistance do not hesitate in contacting me.

Sincerely,

Robert May
AKRON RUBBER DEVELOPMENT LABORATORY, INC.

RM/dc

PN# 8044

AKRON RUBBER DEVELOPMENT LABORATORY, INC.
300 KENMORE BOULEVARD
AKRON, OHIO 44301
(216) 434-6664

January 8, 1985

Ms. Pauline Bennet
Sandia National Laboratories, Inc.
1515 Eubank Blvd.
Albequerque, New Mexico 87123

SUBJECT: Mixing and curing six EPDM compounds as requested by the above company Per PO# 21-8494.

RECEIVED: Six EPDM Recipes

FORMULAE:

	1	2	3	4	5	6
Nordel 2722	90.0	90.0	90.0	90.0	90.0	90.0
DYNH No. 1	20.0	20.0	20.0	20.0	20.0	20.0
Zinc Oxide	5.0	5.0	5.0	5.0	5.0	5.0
Paraffin wax	5.0	5.0	5.0	5.0	5.0	5.0
Zetax	2.0	2.0	2.0	2.0	2.0	2.0
Aminox	1.0	1.0	1.0	1.0	1.0	1.0
Translink 37	60.0	60.0	60.0	-	-	60.0
Silane A-172	1.0	1.0	1.0	1.0	1.0	-
SRF N774	2.0	2.0	2.0	2.0	2.0	2.0
Litharge	5.0	5.0	5.0	5.0	5.0	5.0
DiCup R	5.0	5.0	5.0	5.0	5.0	5.0
Dechlorane +25	33.0	-	-	33.0	33.0	33.0
Antimony Oxide	12.0	-	12.0	12.0	12.0	12.0
Burgess KE	-	-	-	60.0	-	-
Whiting	-	-	-	-	60.0	-
Saytex 102	-	-	33.0	-	-	-
Totals	241.0	196.0	241.0	241.0	241.0	240.0

January 8, 1985

Ms. Pauline Bennet
Sandia National Laboratories, Inc.

RHEOMETER DATA, ASTM D 2084

MODEL: MPV DIE: Micro ARC: 1° SPEED: 100 cpm
TEMPERATURE: 340°F RANGE: 100 CLOCK: 30 minute
350°F

	340°F COMPOUND NO. 1	350°F COMPOUND NO.1
Maximum Torque, MH, Lbf.IN	48.90	47.50
Minimum Torque, ML, Lbf.IN	6.50	6.20
Scorch Time, TS.1, Minutes	2.37	1.50
Cure Time, TC.90, Minutes	12.75	7.00
Cure Rate, $\frac{ML90 - ML}{TC90 - TS.1}$, Lbf.IN/Minute	3.68	6.76

10, 6" x 6" x .075" slabs press cured 15 minutes at 340°F, 1500 psi pressure applied.

Cured slabs shipped via Federal Express January 4, 1985

MIXING SPECIFICATION

TIME	INGREDIENT
0	Nordell 2722, DYNH No. 1
1 min.	Zinc Oxide, Paraffin, Zetax, Aminox, White Fillers, Silane A172, SRF N774, Litharge, Antimony Oxide, Dechlorane +25, Saytex 102
5 min.	Sweep down
5 ½ min.	Dump

DUMP TEMPERATURE: 325°F

Dicup R added on mill at 170°F
Total Mill Time: 3.5 minutes

Compy of rheometer graphs enclosed.

William Klingensmith

William Klingensmith
President

AKRON RUBBER DEVELOPMENT LABORATORY, INC.

PN# 8044
INV# 15286

Appendix B

Instrumentation and Calibration Records

APPENDIX B

Measurement Equipment

Measurement	Manufacturer, Model No.	Accuracy	Calibration Date Calibrated	Calibration Date Expires
Load Voltage Current and Power	Magtrol Power Analyzer Model No. 4612 S/N 1A167	Voltage: ±0.3% ± 5 counts Current: ±0.3% ± 5 counts Power: ±0.3% ± 5 counts	Dec. 10, 1984	Sept. 10, 1985
Insulation Resistance	Hipotronics Megohmmeter Model No. HM3A S/N 9402-00		June 5, 1985	Dec. 5, 1985
Insulation Resistance	Hipotronics AC Dielectric Test Set Model 715-10 Type CS14-1630 S/N 275CS14	±3%	July, 1985	April 24, 1986
Hipot	Hipotronics Hipot Tester Model HD140 S/N K120-1139	±3%	July, 1985	Nov. 1, 1985
Resistance	Hewlett Packard Digital Multimeter S/N 02898	±10%		
Temperature	Omega Type K Thermocouples Type SCASS-0629-6	±0.2°C	Nov. 29, 1984	-
Chamber Pressure	Digital Heise Gauge Model 710A Serial S7-5982	±0.1%	July 22, 1985	Feb. 1, 1986
Analog Data	Hewlett Packard Chart Recorders Model 7132A R18344 and R18342	Trend indicator only (calibration performed before and after test)		
Air Flow Rate	Kurz Air Velocity Meter Model 441			
Data Recording	Acurex Datalogger Model A Ten/10 S/N 274389	Volts ± 0.1% ± 0.10V Thermocouple ± 0.3% ± 0.1°C.	August 23, 1985	Feb. 23, 1986
	Acurex Datalogger Model A Ten/10 S/N 14892	Volts ± 0.1% ± 0.10V Thermocouple ± 0.3% ± 0.1°C	May 21, 1985	Nov. 21, 1985
	Acurex Datalogger Model A Ten/10 S/N 12793	Volts ± 0.1% ± 0.10V Thermocouple ± 0.3% ± 0.1°C	April 14, 1985	Oct. 4, 1985
	Acurex Datalogger Model 800 S/N 9-098	Volts: 55 mV - 10 V range (± 0.03% of reading ± 0.012% of range) Thermocouple ± 0.5°C		
Weight	Ohaus Brainweigh Model B300D S/N 11367	Calibrated at use with with SNLA weights #27412	March 18, 1985 Weights: Jan. 12, 1984	Feb. 1, 1988 Jan. 12, 1987
Thickness	Mitutoyo Micrometer 0-1"; .001" S/N 637	Calibrated at use with SNLA gage Blocks #523		
Tensile Measurements	INSTRON Tensile Measurement Model	Load cell calibrated at use with SNLA weights #4445	Weights: June 16, 1983	June 16, 1986

Appendix C

IR Measurements after One Minute at 500 V: Raw Data

IR MEASUREMENTS [ohms]
(All readings after one minute at 500V.)

Cable	7/26/85 7/29/85 Unaged (Baseline)	8/12/85 8/14/85 After Aging	8/26/85 1st 340°F Peak	8/26/85 2nd 340°F Peak	8/26/85 320°F Plateau	8/26/85 300°F Plateau	8/27/85 Meas. #1 250°F Plateau	8/29/85 Meas. #2 250°F Plateau	8/30/851 Meas. #1 221°F Plateau
A: EPR D lot 1									
Ground/White	2.9 E11	4.6 E11	4.4 E6	3.1 E6	4.9 E6	8.5 E6	7.5 E7	2.85 E7	9.5 E7
Ground/Black	3.9 E11	3.3 E11	4.7 E6	3.7 E6	6.0 E6	1.0 E7	9.9 E7	3.3 E7	1.05 E8
Ground/Red	3.2 E11	3.2 E11	4.2 E6	3.7 E6	6.0 E6	1.02 E7	9.0 E7	4.2 E7	1.14 E8
Cond/Cond	> E12	> E12	1.3 E7	1.0 E7	3.3 E7	1.56 E8	1.18 E9	1.12 E9	3.5 E9
B: EPR D lot 1									
Ground/White	2.7 E11	4.0 E11	5.2 E6	4.3 E6	6.9 E6	1.1 E7	1.0 E8	3.6 E7	1.1 E8
Ground/Black	3.4 E11	2.6 E11	5.5 E6	4.9 E6	8.5 E6	1.31 E7	1.2 E8	4.2 E7	1.2 E8
Ground/Red	3.8 E11	2.7 E11	5.2 E6	5.3 E6	9.7 E6	1.49 E7	1.28 E8	6.9 E7	1.73 E8
Cond/Cond	> E12	> E12	3.3 E7	2.85 E7	7.8 E7	2.41 E8	1.79 E9	1.55 E9	4.8 E9
C: Unaged EPR D lot 1		(Baseline)							
Ground/White		3.5 E11	7.0 E8	2.9 E8	7.0 E8	1.26 E9	2.58 E9	4.9 E8	1.0 E9
Ground/Black		2.8 E11	6.1 E8	3.0 E8	7.0 E8	1.27 E9	3.4 E9	6.5 E8	1.15 E9
Ground/Red		2.8 E11	5.6 E8	2.48 E8	4.7 E8	7.2 E8	2.5 E9	5.9 E8	1.1 E9
Cond/Cond		> E12	6E9 -2E10	8.0 E9	9.9 E9	1.59 E10	3.6 E10	3.5 E9	7.5 E9
D: Unaged EPR D lot 1		(Baseline)							
Ground/White		2.7 E11	6.5 E8	2.52 E8	5.2 E8	9.7 E8	2.19 E9	4.4 E8	9.0 E8
Ground/Black		2.8 E11	5.2 E8	2.48 E8	5.2 E8	1.0 E8	2.67 E9	5.7 E8	1.03 E9
Ground/Red		4.2 E11	4.8 E8	1.9 E8	3.5 E8	5.5 E8	2.11 E9	5.2 E8	1.0 E9
Cond/Cond		> E12	4E9 -1E10	3.0 E9	4.9 E9	1.7 E10	2.5 E10	3.4 E9	6.5 E9
E: EPR D lot 2									
Ground/White	2.1 E11	2.0 E11	1.65 E6	1.29 E6	2.15 E6	3.2 E6	2.97 E7	1.77 E7	5.7 E7
Ground/Black	3.2 E11	2.0 E11	1.67 E6	1.48 E6	2.21 E6	3.25 E6	3.2 E7	1.92 E7	6.5 E7
Ground/Red	2.5 E11	2.2 E11	1.96 E6	1.64 E6	2.50 E6	3.8 E6	4.1 E7	2.62 E7	1.0 E8
Cond/Cond	> E12	> E12	4.3 E6	2.42 E6	7.0 E6	1.1 E8	3.6 E9	1.9 E9	8. E9
F: EPR D lot 2									
Ground/White	2.4 E11	2.7 E11	1.84 E6	1.66 E6	2.7 E6	4.2 E6	4.1 E7	2.47 E7	8.0 E7
Ground/Black	2.15 E11	1.76 E11	1.99 E6	1.72 E6	2.7 E6	4.1 E6	4.0 E7	2.3 E7	7.0 E7
Ground/Red	2.5 E11	2.5 E11	2.4 E6	2.1 E6	3.5 E6	5.5 E6	5.8 E7	3.7 E7	1.3 E7
Cond/Cond	> E12	> E12	7.4 E6	4.9 E6	2.44 E7	1.86 E8	5.5 E9	4.9 E9	9E9-1E10

*Measurement taken at one minute--but not stable.

IR MEASUREMENTS [ohms] (continued)

Cable	9/2/85 Meas.#2 221°F Plateau	9/3/85 Meas.#3 221°F Plateau	9/5/85 Meas.#4 221°F Plateau	9/6/85 Meas.#5 221°F Plateau	9/9/85 Meas.#6 221°F Plateau	9/11/85 Meas.#7 221°F Plateau	9/13/85 Meas.#8 221°F Plateau	9/16/85 Meas.#9 221°F Plateau	9/16/85 Posttest
A: EPR D lot 1									
Ground/White	4. E7	3.8 E7	3.3 E7	2.99 E7	3.2 E7	3.2 E7	3.1 E7	< 1.0 E6	--
Ground/Black		5.0 E7	4.2 E7	4.0 E7	4.5 E7	4.5 E7	4.7 E7		--
Ground/Red		2.3 E7	3.2 E7	2.2 E7	9.5 E6*	3.8 E6	3.0 E6		--
Cond/Cond		2.0 E9	1.1 E9	8.0 E8	4.2 E8	3.0 E8	2.0 E8		--
B: EPR D lot 1									
Ground/White	5.0 E7	4.8 E7	4.1 E7	3.7 E7	3.8 E7	3.8 E7	3.7 E7	< 1.0 E6	--
Ground/Black		6.0 E7	5.2 E7	4.8 E7	5.0 E7	5.0 E7	5.2 E7		--
Ground/Red		8.0 E7	5.9 E7	5.0 E7	1.6 E7	9.5 E6	6.0 E6		--
Cond/Cond		4.6 E9	3.6 E9	3.5 E9	2.0 E9	1.3 E9	7.5 E8		--
C: Unaged EPR D lot 1									
Ground/White	5.2 E8	5.1 E8	4.7 E8	4.5 E8	4.6 E8	4.7 E8	4.5 E8	5 E8	1.9 E11
Ground/Black		7.0 E8	6.5 E8	6.0 E8	6.8 E8	7.0 E8	4.7 E8		2.0 E11
Ground/Red		6.5 E8	5.5 E8	5.7 E8	6.0 E8	6.2 E8	6.3 E8		1.7 E11
Cond/Cond		6.8 E9	5.9 E9	6.0 E9	6.0 E9	6.0 E9	6.6 E9		> E13
D: Unaged EPR D lot 1									
Ground/White	4.8 E8	4.8 E8	4.3 E8	4.1 E8	2.5 E8	4.2 E8	4.0 E8	4.5 E8	1.9 E11
Ground/Black		6.7 E8	5.9 E8	5.7 E8	6.0 E8	6.0 E8	5.9 E8		1.9 E11
Ground/Red		6.0 E8	5.0 E8	5.0 E8	5.2 E8	5.6 E8	5.8 E8		1.8 E11
Cond/Cond		6.5 E9	5.5 E9	6.0 E9	6.0 E9	6.2 E9	6.5 E9		> E13
E: EPR D lot 2									
Ground/White	3.4 E7	3.0 E7	2.9 E7	1.1 E7	1.7 E7	1.5 E7	1.28 E7	1.1 E7	1.8 E10
Ground/Black		3.2 E7	2.49 E7	2.1 E7	1.7 E7	1.4 E7	1.15 E7		7.0 E9
Ground/Red		5.8 E7	4.8 E7	4.5 E7	4.0 E7	3.8 E7	3.5 E7		4.2 E7
Cond/Cond		3.7 E9	2.7 E9	2.4 E9	2.32 E9	2.1 E9	1.7 E9		> E13
F: EPR D lot 2									
Ground/White	4.5 E7	4.0 E7	3.2 E7	2.7 E7	2.3 E7	2.0 E7	1.74 E7	1.5 E7	2.4 E10
Ground/Black		3.2 E7	2.35 E7	1.95 E7	1.5 E7	1.25 E7	1.0 E7		2.8 E9
Ground/Red		7.8 E7	6.0 E7	5.7 E7	5.2 E7	5.0 E7	4.5 E7		5.5 E10
Cond/Cond		4.2 E9	2.3 E9	3.0 E9	2.85 E9	2.3 E9	1.8 E9		> E13

IR MEASUREMENTS [ohms] (continued)
(All readings after one minute at 500V.)

Cable	7/26/85 7/29/85 Unaged (Baseline)	8/12/85 8/14/85 After Aging	8/26/85 1st 340°F Peak	8/26/85 2nd 340°F Peak	8/26/85 320°F Plateau	8/26/85 300°F Plateau	8/27/85 Meas. #1 250°F Plateau	8/29/85 Meas. #2 250°F Plateau	8/30/851 Meas. #1 221°F Plateau
G: EPRD lot 1									
Multiplex									
Ground/White	5.6 E11	2.8 E11	3 E7	4.4 E7	7.1 E7	1.06 E8	7.1 E8	1.1 E9	3.4 E9
Ground/Black	5.5 E11	4.5 E11	4.3 E7	5.0 E7	8.5 E7	1.25 E8	4.3 E8	1.14 E9	3.8 E9
Ground/Red	6.2 E11	4.5 E11	4.1 E7	4.6 E7	6.5 E7	1.0 E8	7.9 E8	9.7 E8	3.2 E9
Cond/Cond	> E12	> E12	1.5 E8	3.2 E8	1.33 E9	1.70 E10	5.9 E11	7E11-1E12	7. E11
H: EPR D lot 1									
Single	4.1 E11	3.6 E11	9.9 E6	1.0 E8	1.52 E8	2.4 E8	1.9 E9	2.2 E9	7. E9
I: EPR D, lot 2									
Single	3.4 E11	4.2 E11	2 E7	1.44 E7	2.65 E7	6.9 E7	8.7 E8	9.9 E8	3.5 E9
J: EPR H									
Ground/White	1.5 E11	1.5 E11	8.9 E6	6.1 E6	1.09 E7	2.0 E7	1.79 E8	2.05 E8	7.8 E8
Ground/Black	1.57 E11	1.4 E11	1.25 E6	1.43 E6	2.4 E6	3.7 E6	2.85 E7	3.3 E7	1.3 E8
Ground/Red	2.2 E11	1.6 E11	8 E6	6.0 E6	1.09 E7	2.0 E7	1.65 E8	1.92 E8	7.5 E8
Cond/Cond	> E12	> E12	1.87 E8	3.5 E8	8.9 E8	5.0 E9	1.49 E11	2. E11*	4.5 E11
K: EPR H									
Ground/White	1.56 E11	1.47 E11	8.0 E6	7.4 E6	1.22 E7	2.19 E7	1.98 E8	2.15 E8	7.8 E8
Ground/Black	1.64 E11	1.3 E11	1.38 E6	1.61 E6	2.60 E6	3.6 E6	2.65 E7	2.77 E7	1.1 E8
Ground/Red	2.3 E11	1.5 E11	7.3 E6	6.8 E6	1.17 E7	2.06 E7	1.62 E8	1.92 E8	7.5 E8
Cond/Cond	> E12	> E12	2.75 E8	6E8-1E9	7E11-> E13	3E9-1E10	5.2 E11	8E12-1E13	> E13
L: unaged									
EPR H		(Baseline)							
Ground/White		1.52 E11	2.1 E8	1.04 E8	1.3 E8	1.8 E8	7.3 E8	3.8 E8	1.2 E9
Ground/Black		1.7 E11	1.57 E8	8.0 E7	1.01 E8	1.28 E8	5.1 E8	3.4 E8	1.1 E9
Ground/Red		1.7 E11	1.26 E8	7.0 E7	9.9 E7	1.27 E8	5.3 E8	3.4 E8	1.08 E9
Cond/Cond		> E12	3.4 E9	2.6 E9	1.08 E10	2.32 E11	> E12	7.9 E11	6. E11
M: Unaged EPR H		(Baseline)							
Ground/White		1.5 E11	1.37 E8	1.06 E8	1.3 E8	1.81 E8	7.5 E8	4.0 E8	1.25 E9
Ground/Black		1.8 E11	1.85 E8	9.5 E7	1.11 E8	1.41 E8	5.8 E8	3.6 E8	1.18 E9
Ground/Red		1.7 E11	1.36 E8	7.5 E7	9.5 E7	1.37 E8	5.8 E8	3.6 E8	1.12 E9
Cond/Cond		> E12	4.5 E9	2.9 E9	1.14 E10	1.68 E11	> E12	> E12	7. E11
N: EPR H Multiplex									
Ground/White	1.98 E11	2.25 E11	1.29 E7	1.48 E7	1.69 E7	2.48 E7	2.13 E8	1.99 E8	6.0 E8
Ground/Black	4.2 E11	4 E11	1.0 E7	1.32 E7	1.63 E7	2.6 E7	2.15 E8	1.98 E8	6.3 E8
Ground/Red	2.09 E11	2.8 E11	1.24 E7	1.29 E7	1.65 E7	2.7 E7	2.29 E8	2.09 E8	6.5 E8
Cond/Cond	> E12	> E12	2.3 E7	2.23 E7	4.4 E7	6.1 E9	> E12	5 E11*	5 E11
O: EPR H									
Single	2.1 E11	2.8 E11	1.7 E7	1.82 E7	2.2 E7	3.5 E7	3.1 E8	2.74 E8	8.0E8

IR MEASUREMENTS [ohms] (continued)

Cable	9/2/85 Meas.#2 221°F Plateau	9/3/85 Meas.#3 221°F Plateau	9/5/85 Meas.#4 221°F Plateau	9/6/85 Meas.#5 221°F Plateau	9/9/85 Meas.#6 221°F Plateau	9/11/85 Meas.#7 221°F Plateau	9/13/85 Meas.#8 221°F Plateau	9/16/85 Meas.#9 221°F Plateau	9/16/85 Posttest
G: EPR D lot 1									
Multiplex									
Ground/White	5.1E9	5.5E9	5.3E9	6.0E9	6.0E9	6.0E9	5.9E9	8.0E9	1.3E11
Ground/Black		5.5E9	5.3E9	5.5E9	5.2E9	5.2E9	5.0E9		7.0E10
Ground/Red		5.4E9	4.9E9	6.5E9	6.0E9	6.0E9	5.8E9		1.1E11
Cond/Cond		1.4E12	1.4E12	3E12	E12-> E13	> E12	> E13		> E13
H: EPR D lot 1									
Single	8.0E9	9.0E9	7.5E9	6.5E9	7.6E9	8.0E9	8.0E9	1.0E10	1.2E11
I: EPR D lot 2									
Single	4.0E9	4.0E9	3.7E9	3.5E9	3.4E9	3.3E9	3.2E9	3.0E9	1.4E11
J: EPR H									
Ground/White	8.0E8	9.0E8	8.8E8	9.0E8	1.02E9	1.1E9	1.15E9	1.27E9	1.35E11
Ground/Black		1.38E8	1.3E8	1.3E8	1.35E8	1.3E8	1.25E8		7.0E10
Ground/Red		8.0E8	8.0E8	9.0E8	1.0E9	1.0E9	1.0E9		1.25E11
Cond/Cond		4E11-1E12	8.0E11	> E12	> E13	> E12	> E13		> E13
K: EPR H									
Ground/White	8.0E8	8.5E8	8.2E8	9.0E8	9.9E8	1.02E9	1.16E9	1.16E9	1.4E11
Ground/Black		1.2E8	1.17E8	1.1E8	1.1E8	1.08E8	1.02E8		7.0E10
Ground/Red		7.7E8	7.5E8	8.0E8	8.0E8	9.0E8	9.3E8		1.5E11
Cond/Cond		5E11-3E12	3E11-E13	5E11-> E12	E12	4E11-> E12	5E11-> E13		> E13
L: Unaged EPR H									
Ground/White	1.06E9	1.08E9	1.04E9	1.05E9	1.1E9	1.13E9	1.13E9	1.2E9	2.5E11
Ground/Black		1.0E9	1.02E9	1.0E9	1.05E9	1.08E9	1.09E9		2.4E11
Ground/Red		1.01E9	9.8E8	1.0E9	1.05E9	1.08E9	1.08E9		1.3E11
Cond/Cond		8.0E11	8.7E11	> E12	> 5E12	> 5E12	1E13		> E13
M: Unaged EPR H									
Ground/White	1.08E9	1.1E9	1.07E9	1.06E9	1.15E9	1.18E9	1.2E9	1.26E9	1.9E11
Ground/Black		1.0E9	1.0E9	1.0E9	1.08E9	1.1E9	1.12E9		1.9E11
Ground/Red		1.05E9	1.0E9	1.02E9	1.06E9	1.1E9	1.13E9		2.2E11
Cond/Cond		2E12	1.7E12	> E13	> E13	> 5E12	> E13		> E13
N: EPR H Multiplex									
Ground/White	6.0E8	6.4E8	6.9E8	6.8E8	6.5E8	6.8E8	5.0E8	3.9E8	4.8E9
Ground/Black		7.0E8	6.9E8	7.0E8	5.9E8	5.0E8	3.6E8		3.0E9
Ground/Red		6.2E8	6.8E8	6.8E8	8.0E8	8.0E8	7.9E8		4.5E10
Cond/Cond		3E12	9E11-5E13	1E11-> E13	E11-> E12	> E12	> E12-> E13		> E13
O: EPR H									
Single	8.0E8	8.0E8	8.1E8	8.0E8	7.5E8	7.0E8	5.9E8	5.2E8	1.24E10

Appendix D

AC Leakage Current Measurements: Raw Data

AC LEAKAGE CURRENT MEASUREMENTS (mA)

Cable	7/29/85 Baseline 600V, 1 min.	8/14/85 After Aging 600V, 1 min.	9/17 & 19/85 Posttest 600V, 1 min.	9/17 & 19/85 Posttest 1200V, 1 min	9/17 & 19/85 Posttest 1800V, 1 min.	9/17 & 19/85 Posttest 2400V, 5 min.
A: EPR D lot 1						
Ground/White	.56	.45	2.0	4.82	> 750	---
Ground/Black	.59	.4	1.92	4.6	> 750	---
Ground/Red	.57	.4	1.8	4.0	> 750	---
Cond/Cond	.71	.56				
B: EPR D lot 1						
Ground/White	.53	.35	2.3	4.71	> 750	---
Ground/Black	.53	.37	2.3	4.65	> 750	---
Ground/Red	.54	.48	1.8	4.15	> 750	---
Cond/Cond	.72	.56				
C: Unaged EPR D lot 1		(Baseline)				
Ground/White		.5	.82	1.72	2.5	3.4
Ground/Black		.36	.8	1.6	2.42	3.48
Ground/Red		.39	.8	1.65	2.55	3.28
Cond/Cond		.53				
D: Unaged EPR D lot 1		(Baseline)				
Ground/White		.48	.8	1.64	2.7	3.4
Ground/Black		.39	.8	1.72	2.5	3.42
Ground/Red		.39	.8	1.72	2.52	3.4
Cond/Cond		.58				
E: EPR D lot 2						
Ground/White	.58	.48	1.14	2.3	3.65	4.9
Ground/Black	.58	.4	1.2	2.32	3.65	4.9
Ground/Red	.55	.4	1.1	2.22	3.5	4.6
Cond/Cond	.74	.57				
F: EPR D, lot 2						
Ground/White	.49	.45	1.0	2.05	3.15	4.32
Ground/Black	.50	.33	1.0	2.1	3.2	4.9
Ground/Red	.49	.32	.95	1.88	3.02	4.03
Cond/Cond	.67	.53				

AC LEAKAGE CURRENT MEASUREMENTS (mA) (continued)

Cable	7/29/85 Baseline 600V, 1 min.	8/14/85 After Aging 600V, 1 min.	9/17 & 19/85 Posttest 600V, 1 min.	9/17 & 19/85 Posttest 1200V, 1 min	9/17 & 19/85 Posttest 1800V, 1 min.	9/17 & 19/85 Posttest 2400V, 5 min.
G: EPR D lot 1						
Multiplex						
Ground/White	.60	.47	.78	1.75	2.82	4.2
Ground/Black	.60	.44	1.0	2.22	3.6	4.8
Ground/Red	.61	.49	.82	1.85	3.33	4.4
Cond/Cond	.63	.51				
H: EPR D lot 1						
Single	.48	.32	.61	1.6	2.6	3.85
I: EPR D lot 2						
Single	.49	.32	.7	1.4	2.05	2.8
J: EPR H						
Ground/White	.49	.33	.88	1.69	2.7	3.5
Ground/Black	.52	.34	.95	1.95	3.02	4.05
Ground/Red	.51	.38	.78	1.72	2.64	3.45
Cond/Cond	.70	.54				
K: EPR H						
Ground/White	.48	.32	.8	1.86	2.5	3.48
Ground/Black	.48	.3	.95	1.85	2.88	4.08
Ground/Red	.49	.38	.8	1.72	2.6	3.4
Cond/Cond	.66	.51				
L: Unaged EPR H		(Baseline)				
Ground/White		.37	.79	1.68	2.5	3.3
Ground/Black		.31	.79	1.58	2.42	3.2
Ground/Red		.4	.72	1.60	2.45	3.22
Cond/Cond		.54				
M: Unaged EPR H		(Baseline)				
Ground/White		.35	.78	1.62	2.41	3.24
Ground/Black		.34	.81	1.65	2.35	3.22
Ground/Red		.42	.7	1.50	2.35	3.1
Cond/Cond		.57				
N: EPR H Multiplex						
Ground/White	.64	.42	.98	1.8	3.0	4.2
Ground/Black	.62	.48	.8	1.8	2.95	4.02
Ground/Red	.63	.52	.85	1.95	3.1	4.02
Cond/Cond	.65	.55				
O: EPR H						
Single	.45	.39	.62	1.4	2.18	3.42

Appendix E

Summary of Test Deviations

E.1 Problems with Instrumentation

Several problems occurred during the course of the test that had no bearing on the results of the test. The first problem arose as a result of the installation of two pressure transmitters in the GIF cell. The system pressure transmitter was recorded on channel #51 of datalogger "A" and the chamber pressure transmitter was recorded on channel #40 of datalogger "B". Both pressure transmitters gave erroneous readings as a result of the radiation field in the GIF cell. A calibrated digital Heise gauge, installed outside the cell, indicated chamber pressure. Unfortunately, it did not have an output signal which could be recorded on a datalogger. Daily logs and chart recordings were used to periodically record the Heise readings. In addition, several other noncalibrated pressure transmitters were used as secondary sources to track the chamber pressure during the course of the test. Furthermore, except for the superheated-steam portion of the test (the first 11 hours of the test), temperature readings may be used to calculate the saturated-steam pressures.

Several other problems occurred starting on August 27, 1985, the second day of the accident simulation. After the 14:00 scan, the RS-232 output of the "B" datalogger malfunctioned. Due to the structure of the HEMP program, the computer was waiting for the output from the datalogger and, therefore, did not receive data from either datalogger.

Also the paper tape output from both dataloggers was maintained until 15:00 on August 28, 1985. But at 15:00 on August 28, 1985, the "B" datalogger paper tape output also failed. The "B" datalogger was replaced on August 29, 1985 at 10:00 and the dataloggers and the computer system operated correctly during the remainder of the test.

Due to the diversity and redundancy of the data acquisition system, a continuous recording of data was maintained by the proper operation of the chart recorders and the "A" datalogger (for chamber inlet pressure). Since neither the computer nor the dataloggers are used to control the steam or radiation systems (the system was manually controlled), none of these events affected the intended accident profile.

E.2 Problems During LICA Simultaneous Aging

Two groups of insulation specimens had problems with either maintaining the thermal aging temperature or with leaking LICA cans. Therefore, new insulation specimens were prepared and aged.

During the simultaneous aging, several power outages occurred. The effect of the outages on the accelerated age of the insulation samples was calculated. In each case, the loss of temperature did not affect the experiment since the achieved accelerated age was between 39 and 40 years.

One final problem involved some of the EPR 1483 Batch 5 insulation specimens. These particular specimens were to have 25 Mrad and an equivalent age of 20 years. However, the samples were removed from the aging conditions approximately 8 hours early. This led to an error of approximately 15 percent.

E.3 Problems During the HIACA Simultaneous Aging

Although thermal aging was interrupted three times during aging, the total thermal aging time included only the time when the temperature was between 134°C and 144°C. The calculated time for thermal aging was 168 hours and the achieved time was 167 hours. This led to less than a 1 percent error in the accelerated age.

Although radiation aging was interrupted four times during aging, the radiation exposure was for the required 149 hours.

E.4 Problems During the HIACA Simultaneous Accident

There were deviations from the intended radiation conditions including

1. the time at which the cobalt was changed from 7 groups to 4 groups and

2. two times when the cobalt dropped into the pool discontinuing irradiation.

These two conditions resulted in an achieved dose of 107 Mrad rather than the intended dose of 108 Mrad (less than 1 percent error).

Appendix F

Chemical Analysis

Samples for the Chemical Analysis

Sample	Description
1	Virgin EPR D lot 1: jacket
2	Virgin EPR D lot 1: insulation
3	Virgin EPR D lot 2: jacket
4	Virgin EPR D lot 2: insulation
5	Virgin EPR H: jacket
6	Virgin EPR H: insulation
7	Virgin EPR F: insulation
8	Powder from aged EPR D cable (after the accident simulation)

E.W.D. HUFFMAN, JR., Ph.D.
PRESIDENT

ESTABLISHED 1936

E.W.D. HUFFMAN SR., Ph.D
CHAIRMAN

HUFFMAN LABORATORIES, INC.

3830 HIGH COURT, P.O. Box 777
Wheat Ridge, Colorado 80034
(303) 424-3232

LAB #: 24986
DATE: 02/28/86

PAULINE BENNETT
SANDIA NATIONAL LABS
1515 EUBANK BLVD, SE #957
ALBUQUERQUE, N.M. 87185

Semi-Quantative Emission Spectrographic Analysis

Customer Sample#: SULFATED ASH FROM SAMPLE #8

Element	(Detection Limit)	Units	Found	Element	(Detection Limit)	Units	Found
Al	(.01)	%	L	Co	(5)	PPM	30
Si	(.01)	%	.7	Cr	(10)	PPM	2000
Na	(.02)	%	.02	Cu	(5)	PPM	G(20,000)
K	(.02)	%	G(5)	La	(20)	PPM	N
Fe	(.05)	%	3	Mo	(5)	PPM	30
Mg	(.02)	%	.15	Nb	(20)	PPM	N
Ca	(.05)	%	.7	Ni	(5)	PPM	300
Ti	(.002)	%	.05	Pb	(10)	PPM	1500
Mn	(10)	PPM	300	Sb	(100)	PPM	G(10,000)
Ag	(.5)	PPM	7	Sc	(5)	PPM	N
As	(200)	PPM	700	Sn	(10)	PPM	300
Au	(10)	PPM	N	Sr	(100)	PPM	N
B	(10)	PPM	300	V	(10)	PPM	15
Ba	(20)	PPM	30	W	(50)	PPM	N
Be	(1)	PPM	N	Y	(10)	PPM	L
Bi	(10)	PPM	N	Zn	(200)	PPM	300
Cd	(20)	PPM	N	Zr	(10)	PPM	70
				Th	(100)	PPM	N

G=Greater than value shown
L=Detected but below detection limit shown
N=Not detected

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CUSTOMER #:
01170

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E.W.D. HUFFMAN, SR., Ph.D.
CHAIRMAN

DATE 2/28/86
LAB# 024986
P.O. SEE BELOW
RECD 01/30/86

ANALYSIS REPORT

PAULINE BENNETT
SANDIA NATIONAL LABS
1515 EUBANK BLVD, SE #957
ALBUQUERQUE NM 87185

DOCUMENT # 04-5390

SEQUENCE/ SAMPLE ID	01 906531 1	02 2	03 3	04 4
CHLORINE------%	13.57	8.20	13.48	<0.20
BROMINE--------%	4.86	<0.30	4.97	11.36

SEQUENCE/ SAMPLE ID	05 5	06 6	07 7	08 8
CARBON-------%				8.07
HYDROGEN------%				1.15
CHLORINE------%	11.05	9.61	10.27	13.74
BROMINE-------%	<0.30	<0.30	<0.30	<1.00
SULFATE ASH---%				96.40

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HUFFMAN LABORATORIES, INC.

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Wheat Ridge, Colorado 80034
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March 19, 1986

Pauline Bennett
Sandia National Labs
1515 Eubank Blvd, SE #957
Albuquerque, N.M. 87185

Dear Ms. Bennett,

The following information is given in response to your request for documentation of calibration for the analyses performed on our lab # 24986.

The carbon hydrogen determination was performed by combusting the sample at 1050°C in oxygen, then separating and measuring the resulting carbon dioxide and water. After combustion in a tin capsule (which raises the temperature of the sample to 1600°C) the combustion gases were swept through combustion catalysts and through a cooled tube containing $CaCl_2$ which trapped the water but allowed the carbon dioxide to be swept on through a scrubber to remove nitrogen oxides and into a Coulometrics carbon dioxide coulometer which measures the carbon dioxide. After sweeping all of the carbon dioxide from the $CaCl_2$ tube, the cooling water was turned off and the tube heated to drive off the water which was swept into a heated tube of 1,1 carbonyldiimidazole which quantitatively converts water to carbon dioxide. The resulting carbon dioxide was then swept into another carbon dioxide coulometer for measurement. Primary standard grade anthracene from the British Drug House Chemicals Ltd. was used as a standard.

The emission spectrochemical analysis was performed by first ashing the sample with sulfuric acid, then placing it on a carbon rod, and passing a high voltage electric spark between the sample rod and another carbon rod. The light produced is then separated by passing through a diffraction grating and recorded on film which is then compared to film produced by running internal standards. There were not any appropriate NBS standards available.

The chlorine and bromine determinations were performed by combusting the samples in oxygen and absorbing the combustion gases in a solution of sodium hydroxide and sodium bisulfite, destroying the bisulfite with H_2O_2, adjusting the pH, then titrating the solution with silver nitrate using potentiometric end points from a silver sulfide electrode and double junction reference electrode.

The methods themselves should give repeatable results within $\pm$ 0.3% absolute. For standard materials we used P-chlorobenzoic acid and P-bromobenzoic acid supplied from the British Drug House. On the chlorobenzoic acid which has a theoretical chlorine content of 22.64%, a value of 22.56% was found. On the bromobenzoic acid with a theoretical bromine content of 39.75%, a value of 39.45% was found.

Sincerely,

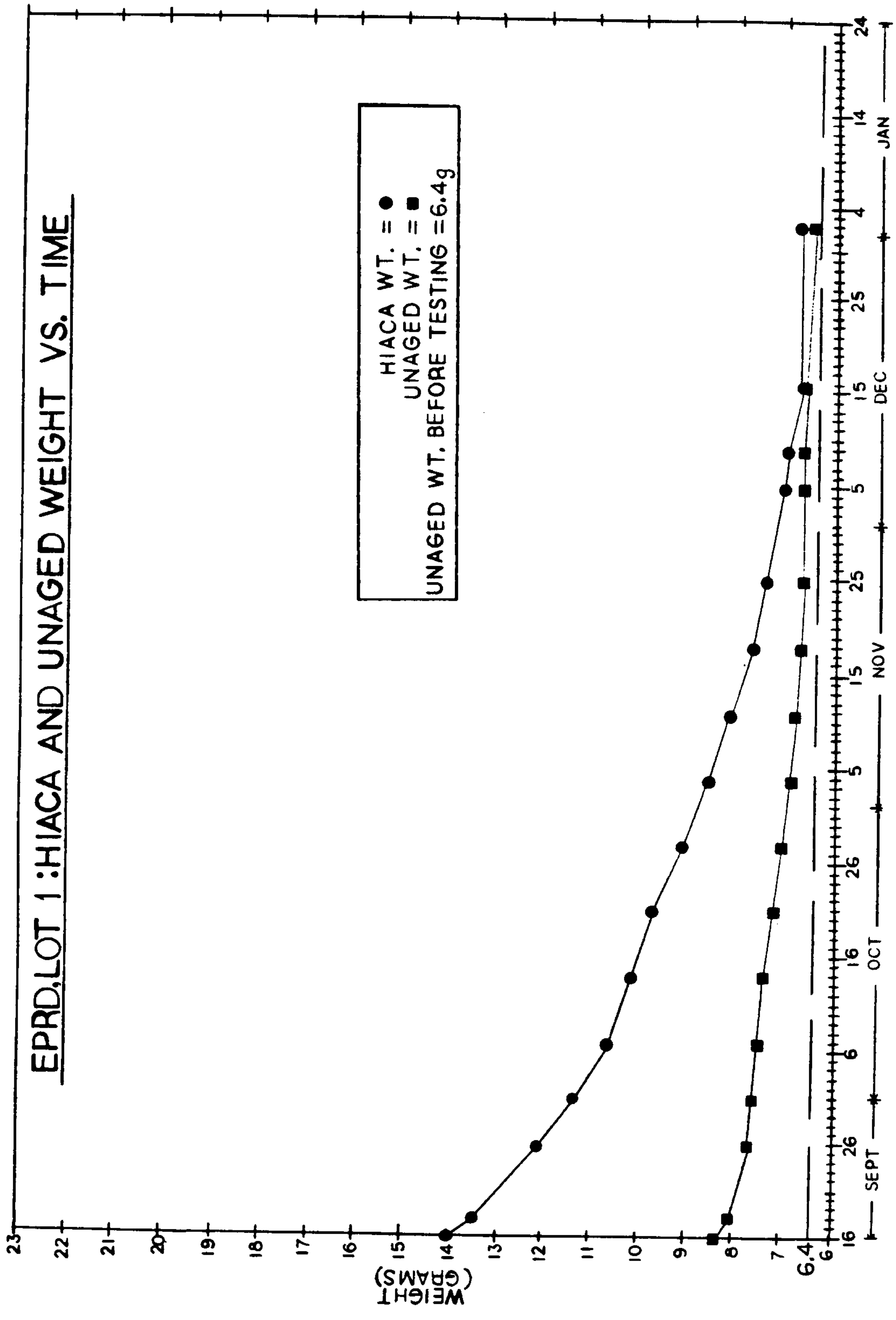
Dale Raines

Dale Raines
Lab Manager

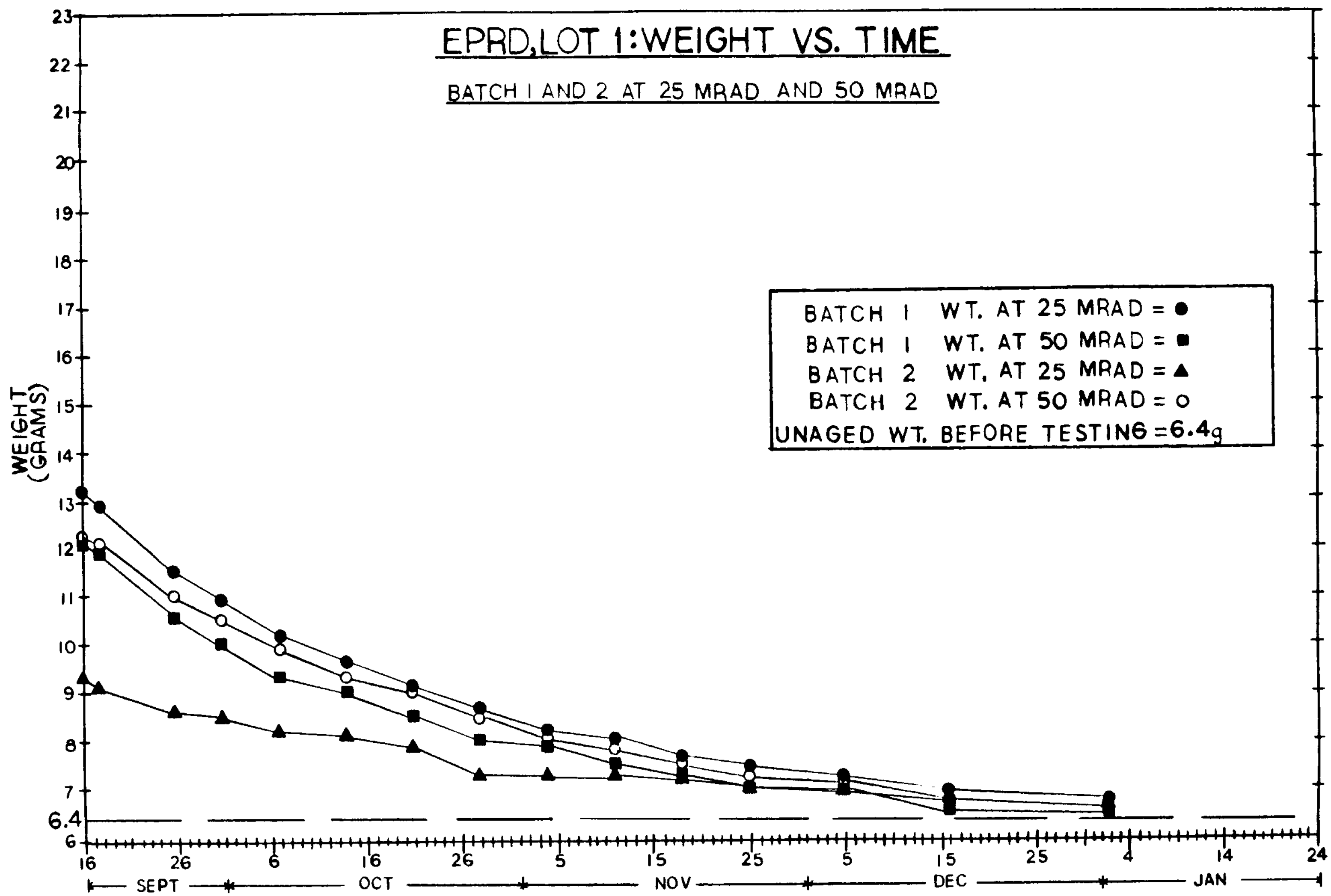
DR/md

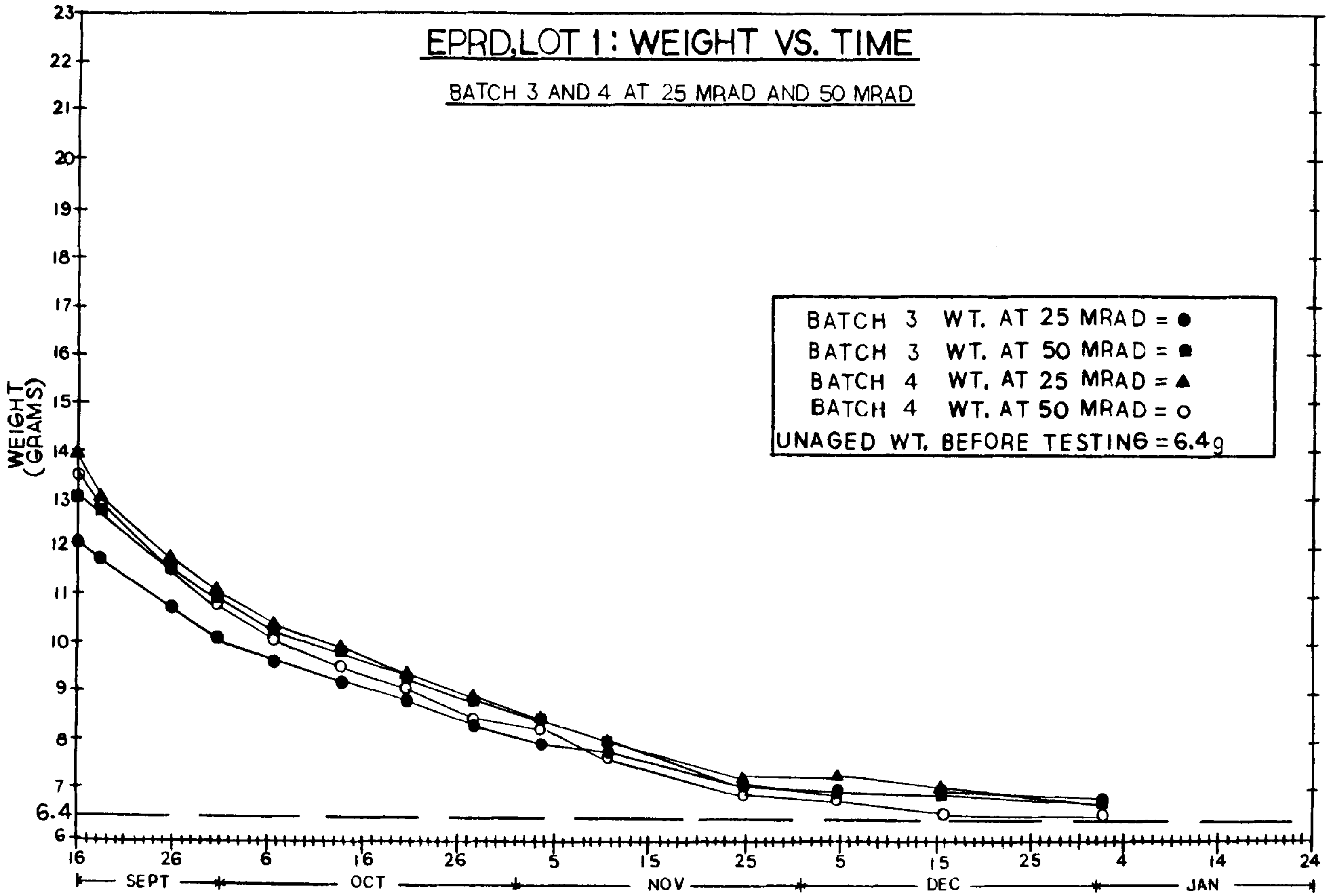
Appendix G

Reduction in Insulation Specimen Weight with Time



EPRD,LOT 1:HIACA AND UNAGED WEIGHT VS. TIME
HIACA WT. = ●
UNAGED WT. = ■
UNAGED WT. BEFORE TESTING =6.4g
WEIGHT (GRAMS)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6.4
6
16
26
SEPT
6
16
OCT
26
5
15
NOV
25
5
15
DEC
25
4
14
JAN
24


EPRD, LOT 1: WEIGHT VS. TIME
BATCH I AND 2 AT 25 MRAD AND 50 MRAD
BATCH I WT. AT 25 MRAD = ●
BATCH I WT. AT 50 MRAD = ■
BATCH 2 WT. AT 25 MRAD = ▲
BATCH 2 WT. AT 50 MRAD = o
UNAGED WT. BEFORE TESTING = 6.4g
WEIGHT (GRAMS)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6.4
6
16
26
6
16
26
5
15
25
5
15
25
4
14
24
SEPT
OCT
NOV
DEC
JAN


EPRD, LOT 1: WEIGHT VS. TIME
BATCH 3 AND 4 AT 25 MRAD AND 50 MRAD
BATCH 3 WT. AT 25 MRAD = ●
BATCH 3 WT. AT 50 MRAD = ■
BATCH 4 WT. AT 25 MRAD = ▲
BATCH 4 WT. AT 50 MRAD = ○
UNAGED WT. BEFORE TESTING = 6.4g
WEIGHT (GRAMS)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6.4
6
16
26
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SEPT
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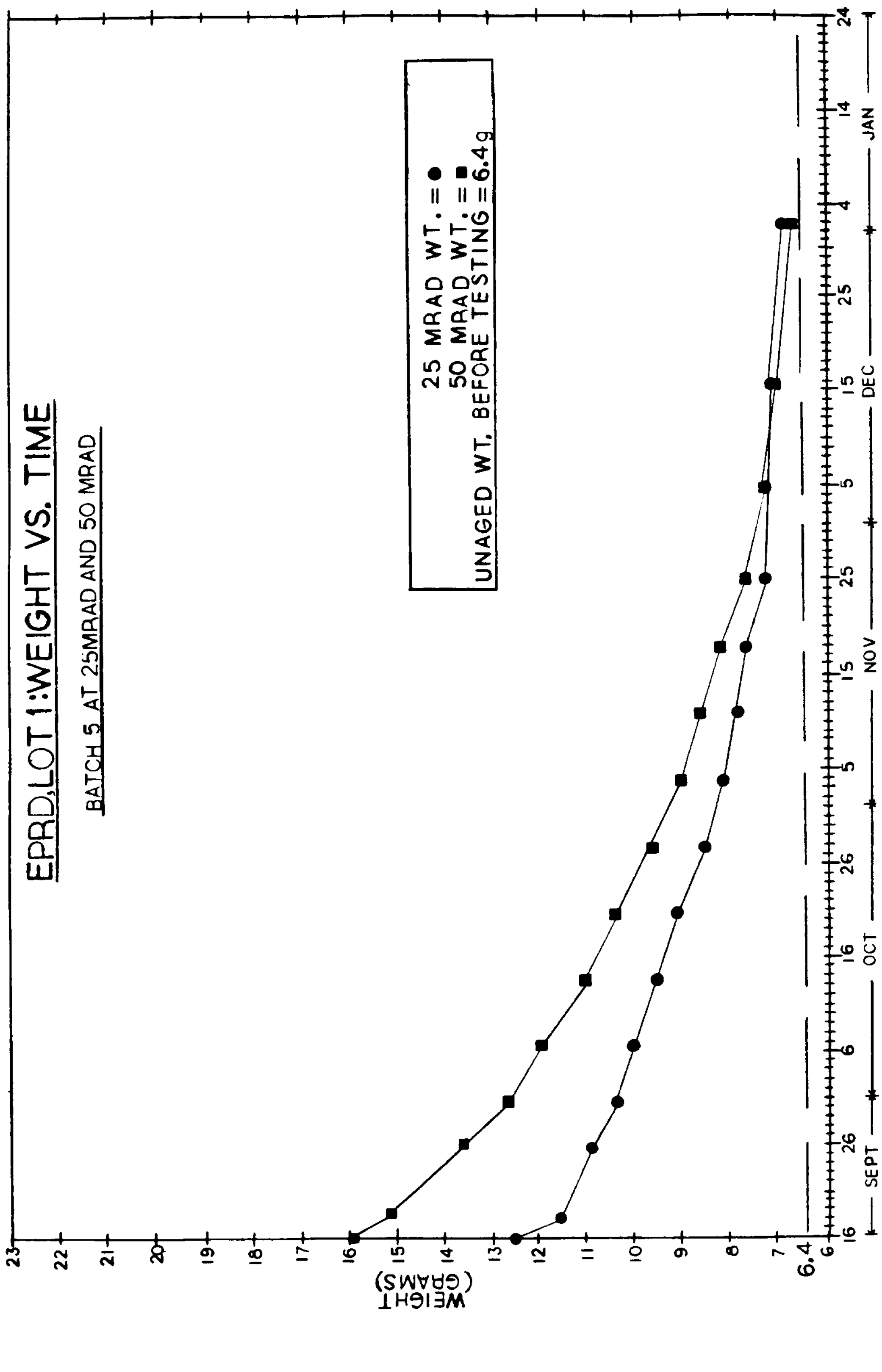
EPRD, LOT 1: WEIGHT VS. TIME
BATCH 5 AT 25 MRAD AND 50 MRAD
25 MRAD WT. = ●
50 MRAD WT. = ■
UNAGED WT. BEFORE TESTING = 6.4 g
WEIGHT (GRAMS)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6.4
6
16
26
6
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26
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24
SEPT
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NOV
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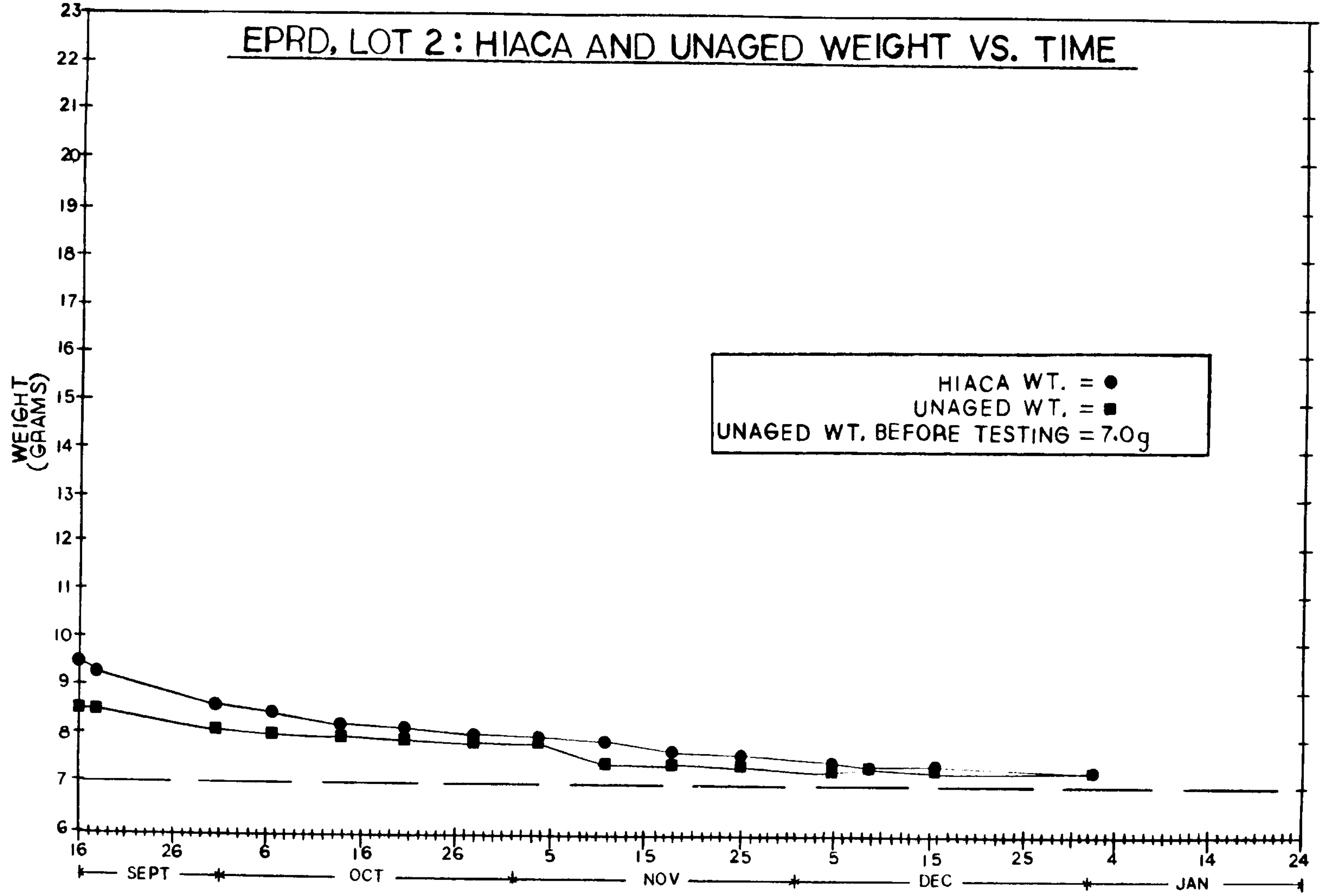
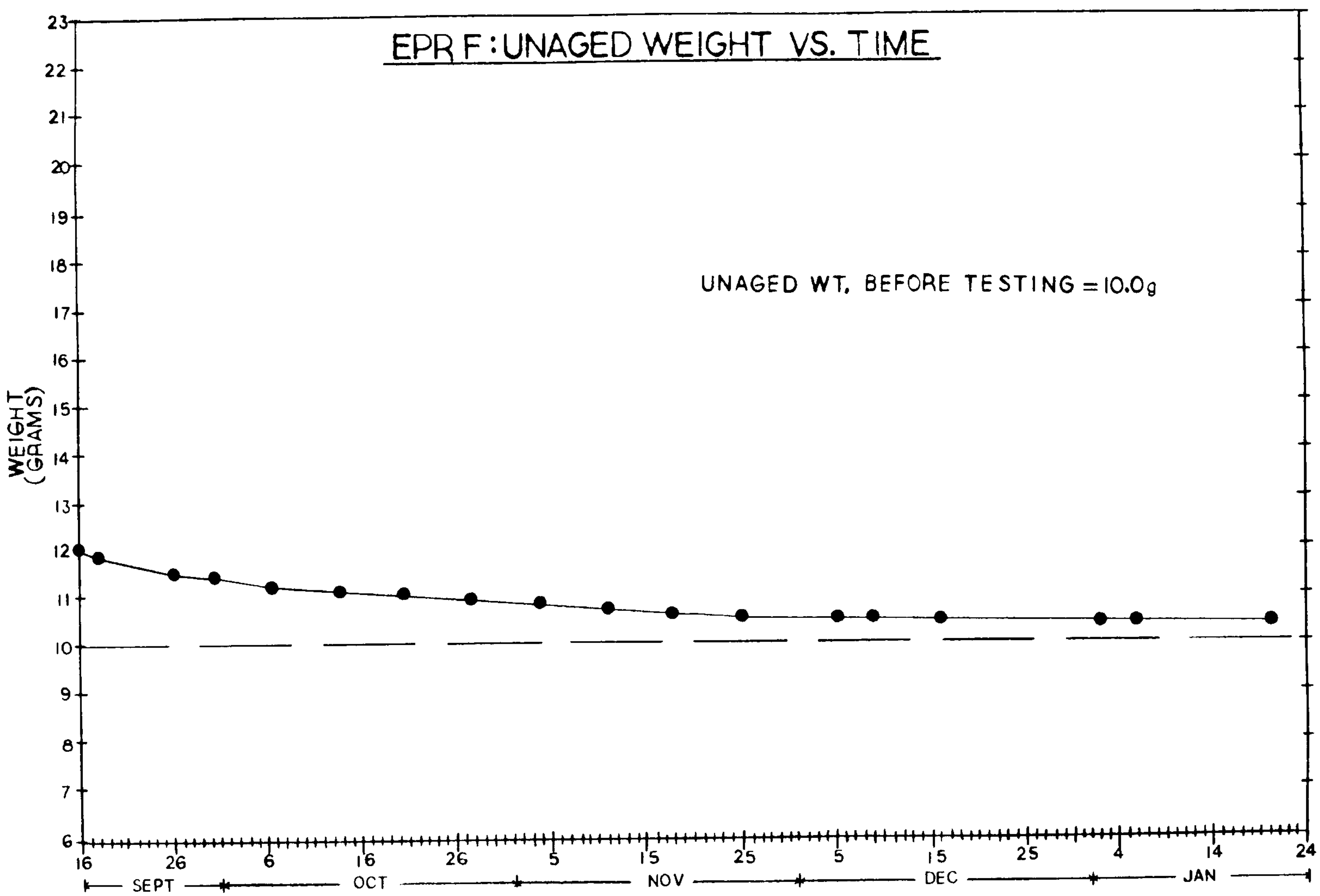
JAN


EPRD, LOT 2: HIACA AND UNAGED WEIGHT VS. TIME
WEIGHT (GRAMS)
HIACA WT. = ●
UNAGED WT. = ■
UNAGED WT. BEFORE TESTING = 7.0g
SEPT
OCT
NOV
DEC
JAN


EPR F: UNAGED WEIGHT VS. TIME
UNAGED WT. BEFORE TESTING = 10.0g
WEIGHT (GRAMS)
23
22
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17
16
15
14
13
12
11
10
9
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SEPT
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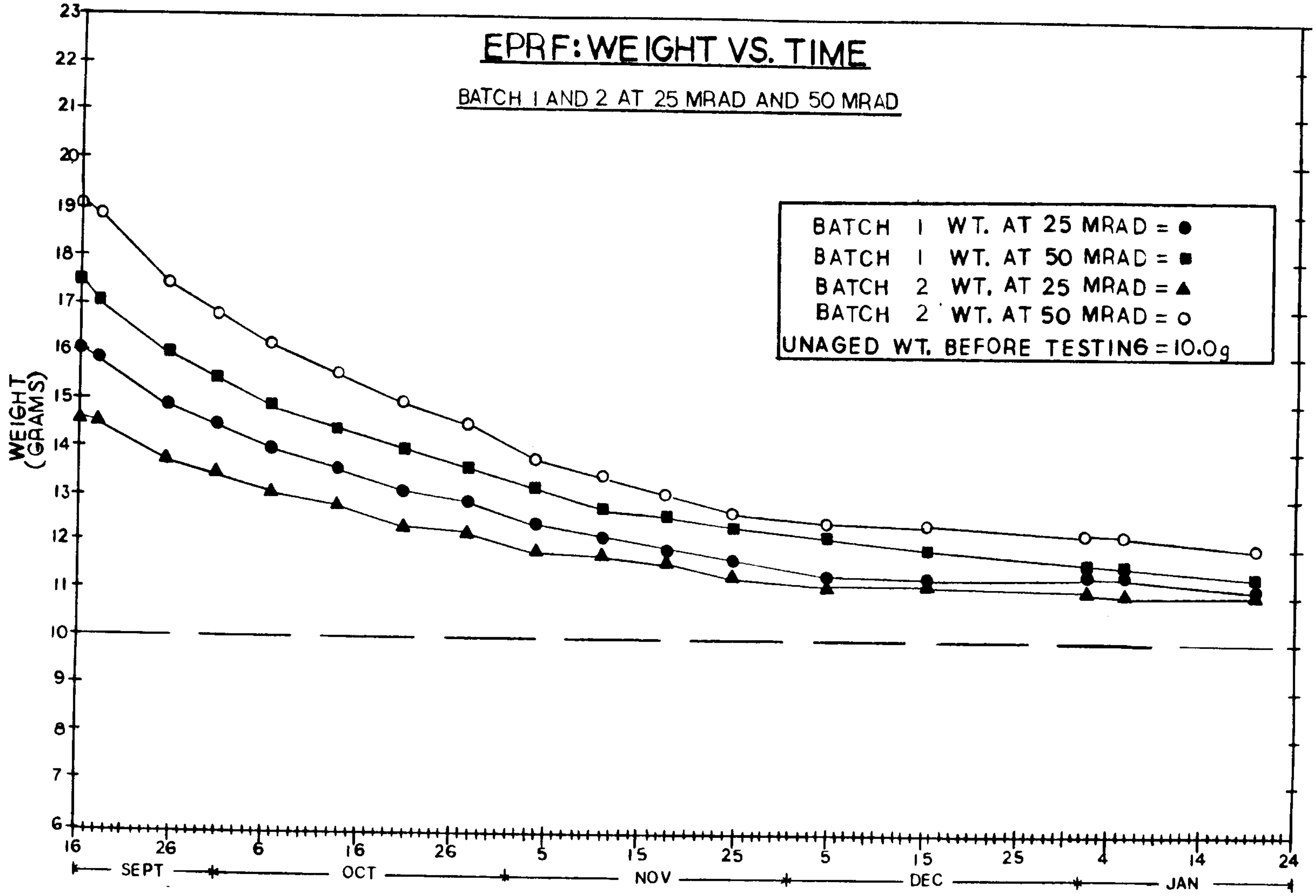
DEC
JAN



EPRF: WEIGHT VS. TIME
BATCH 1 AND 2 AT 25 MRAD AND 50 MRAD
BATCH 1 WT. AT 25 MRAD = ●
BATCH 1 WT. AT 50 MRAD = ■
BATCH 2 WT. AT 25 MRAD = ▲
BATCH 2 WT. AT 50 MRAD = o
UNAGED WT. BEFORE TESTING = 10.0g
WEIGHT (GRAMS)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
16
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6
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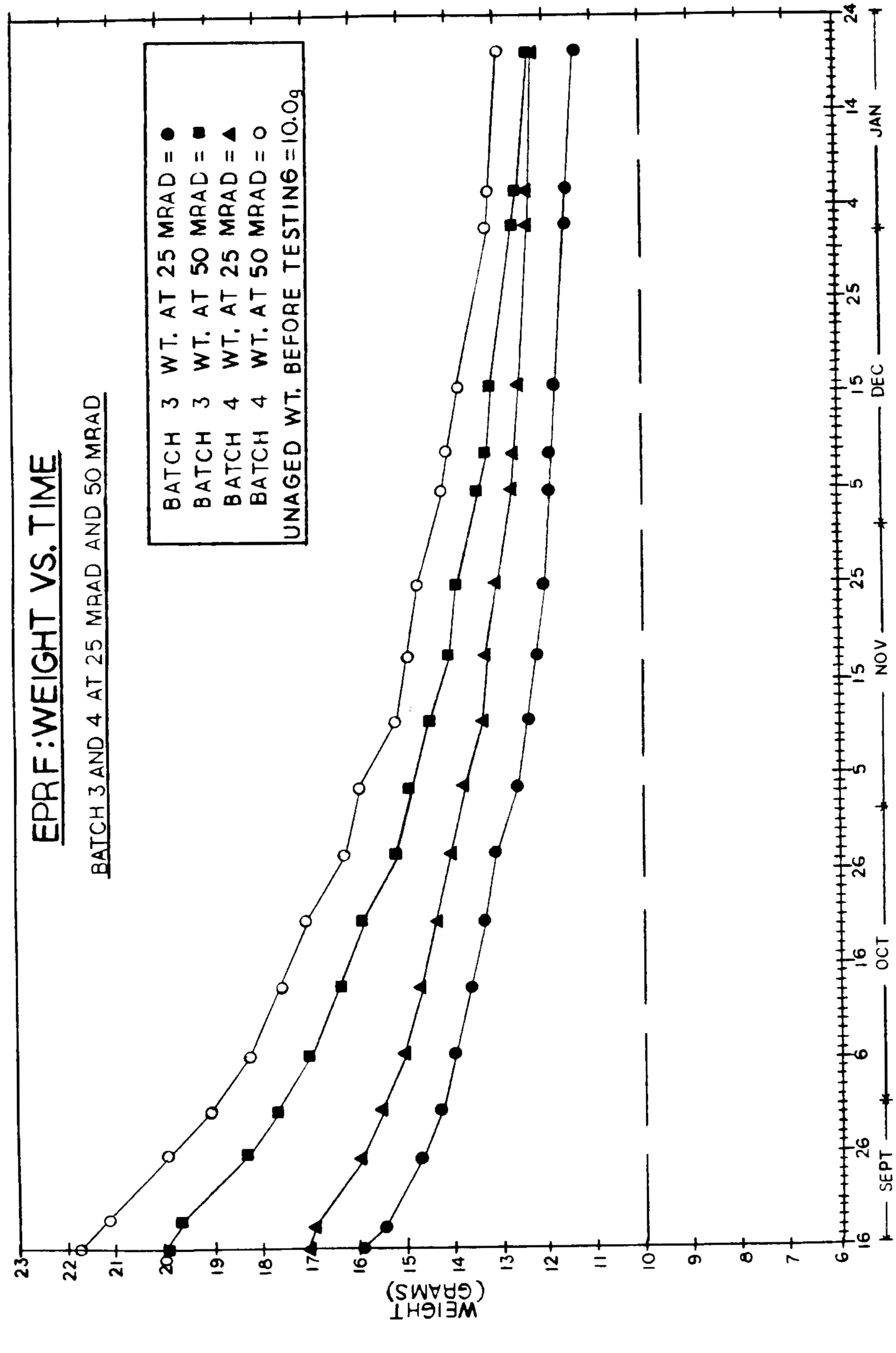
24
SEPT
OCT
NOV
DEC
JAN


EPRF: WEIGHT VS. TIME
BATCH 3 AND 4 AT 25 MRAD AND 50 MRAD
BATCH 3 WT. AT 25 MRAD = ●
BATCH 3 WT. AT 50 MRAD = ■
BATCH 4 WT. AT 25 MRAD = ▲
BATCH 4 WT. AT 50 MRAD = ○
UNAGED WT. BEFORE TESTING = 10.0g
WEIGHT (GRAMS)
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
16
26
6
16
26
5
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5
15
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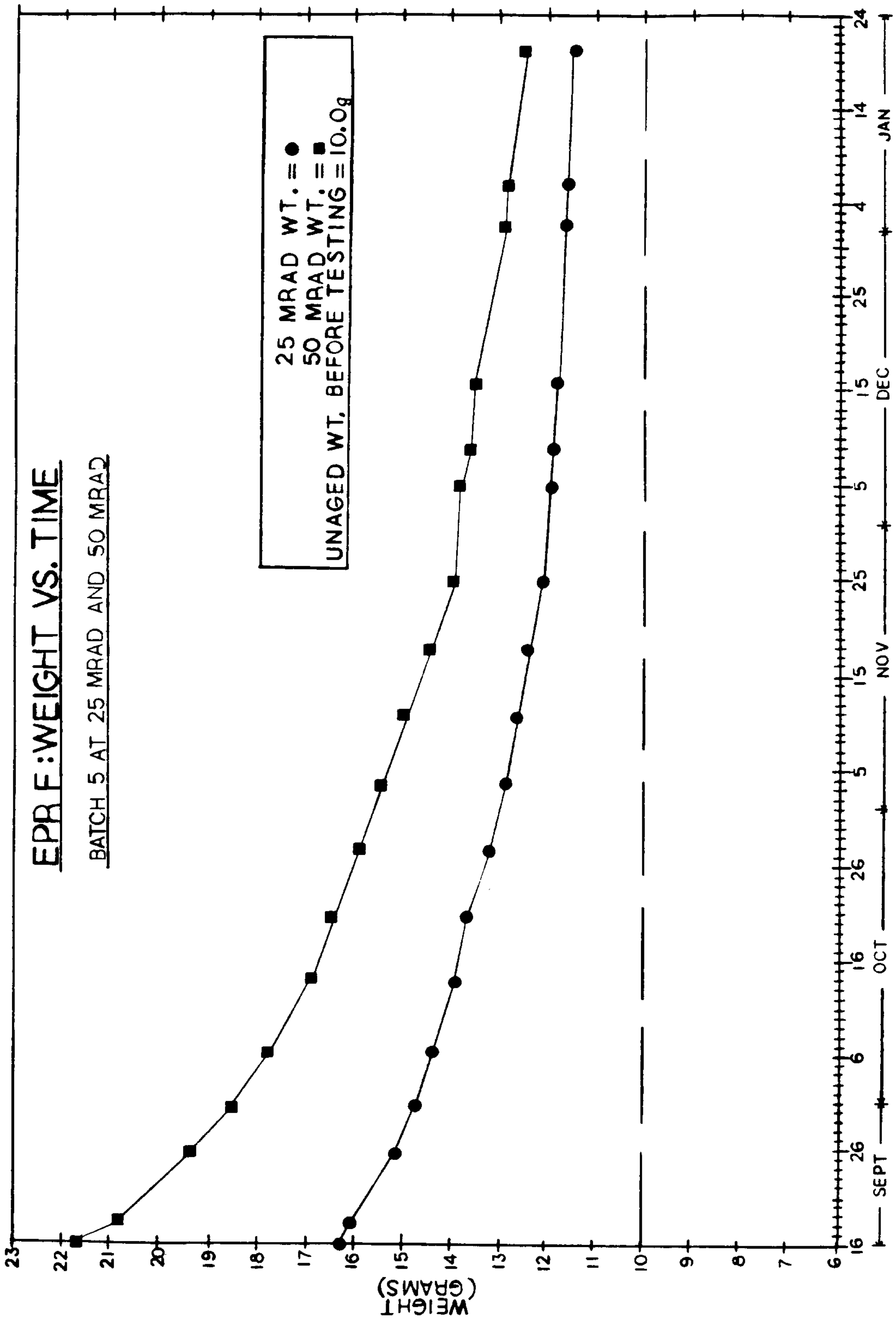
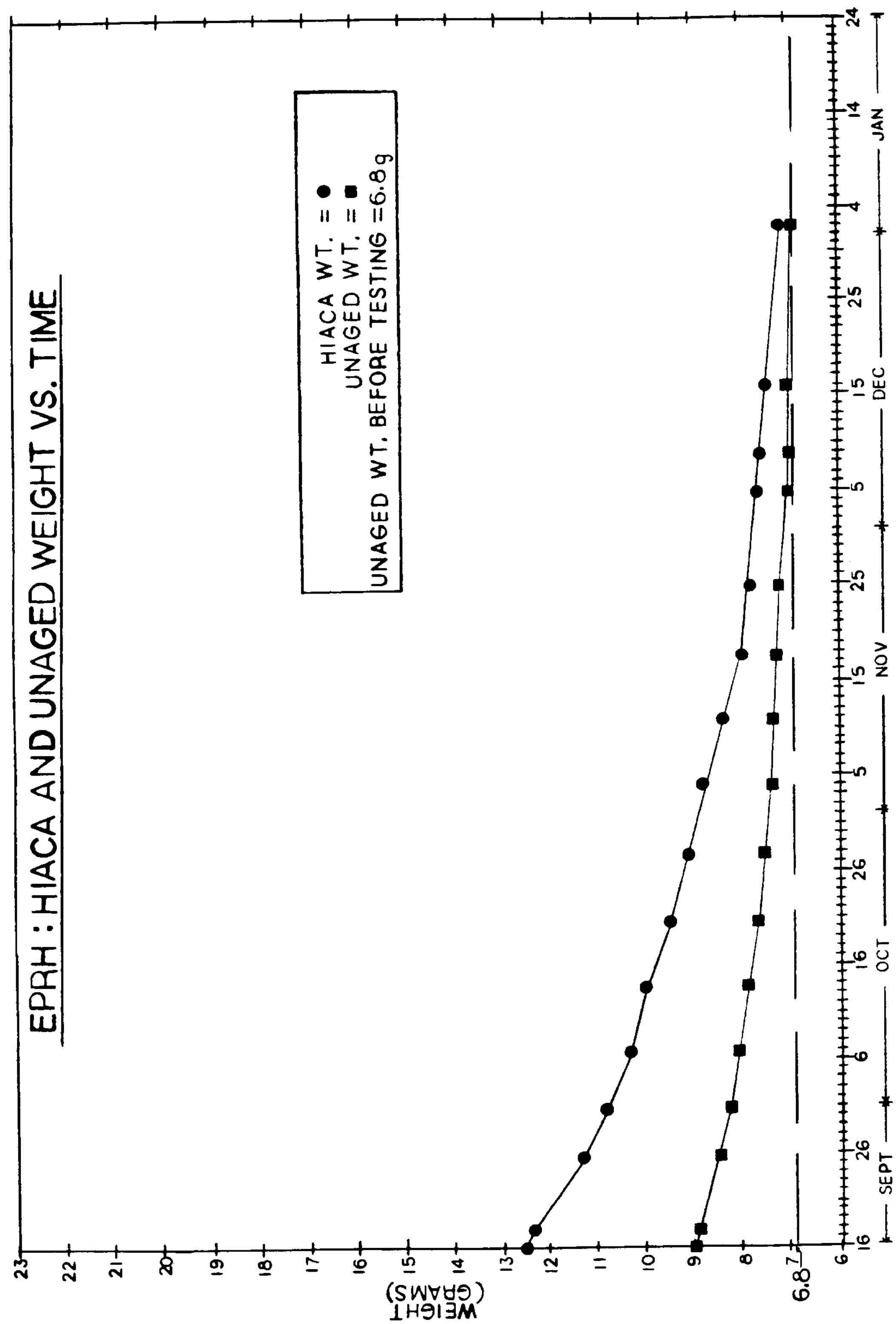
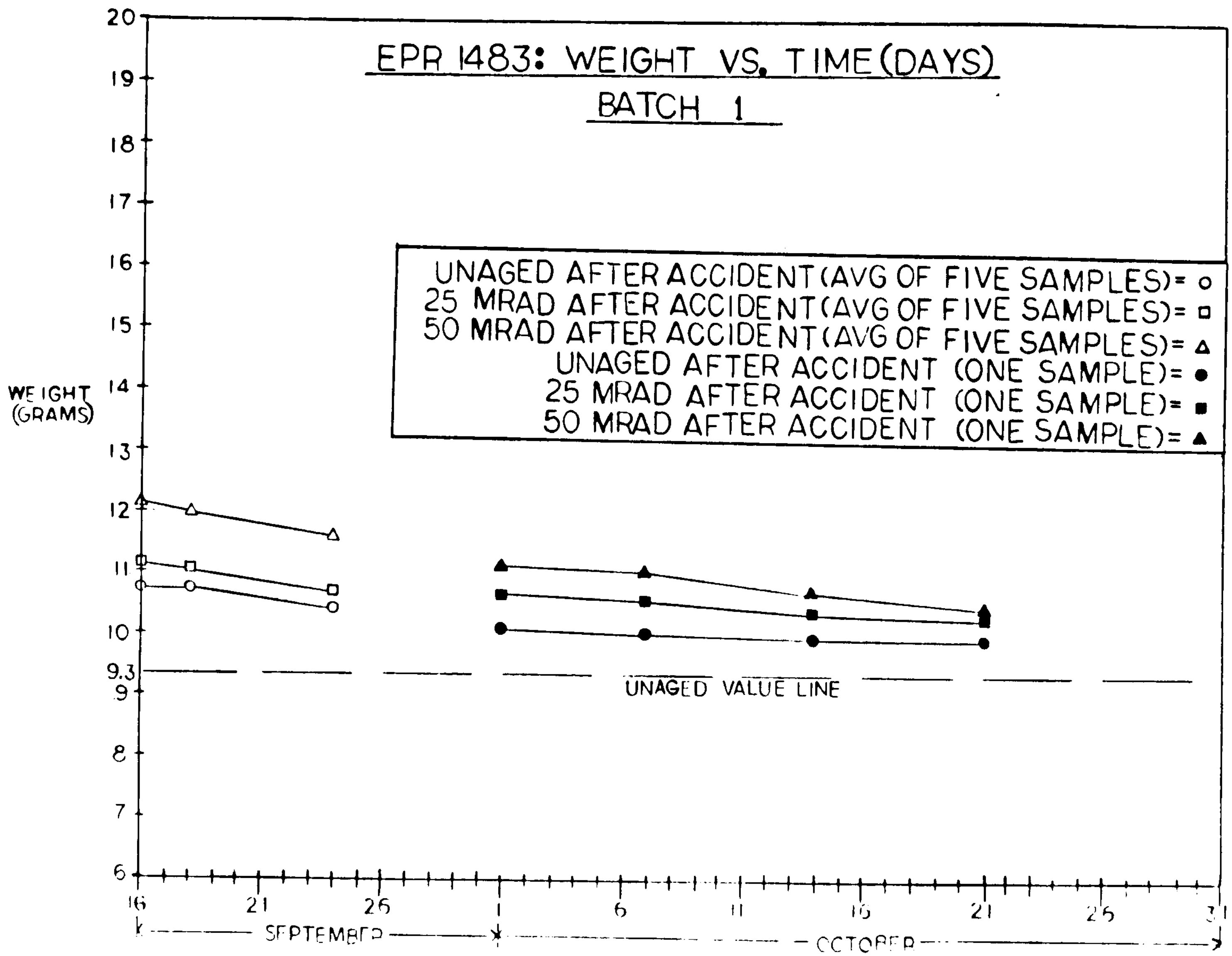
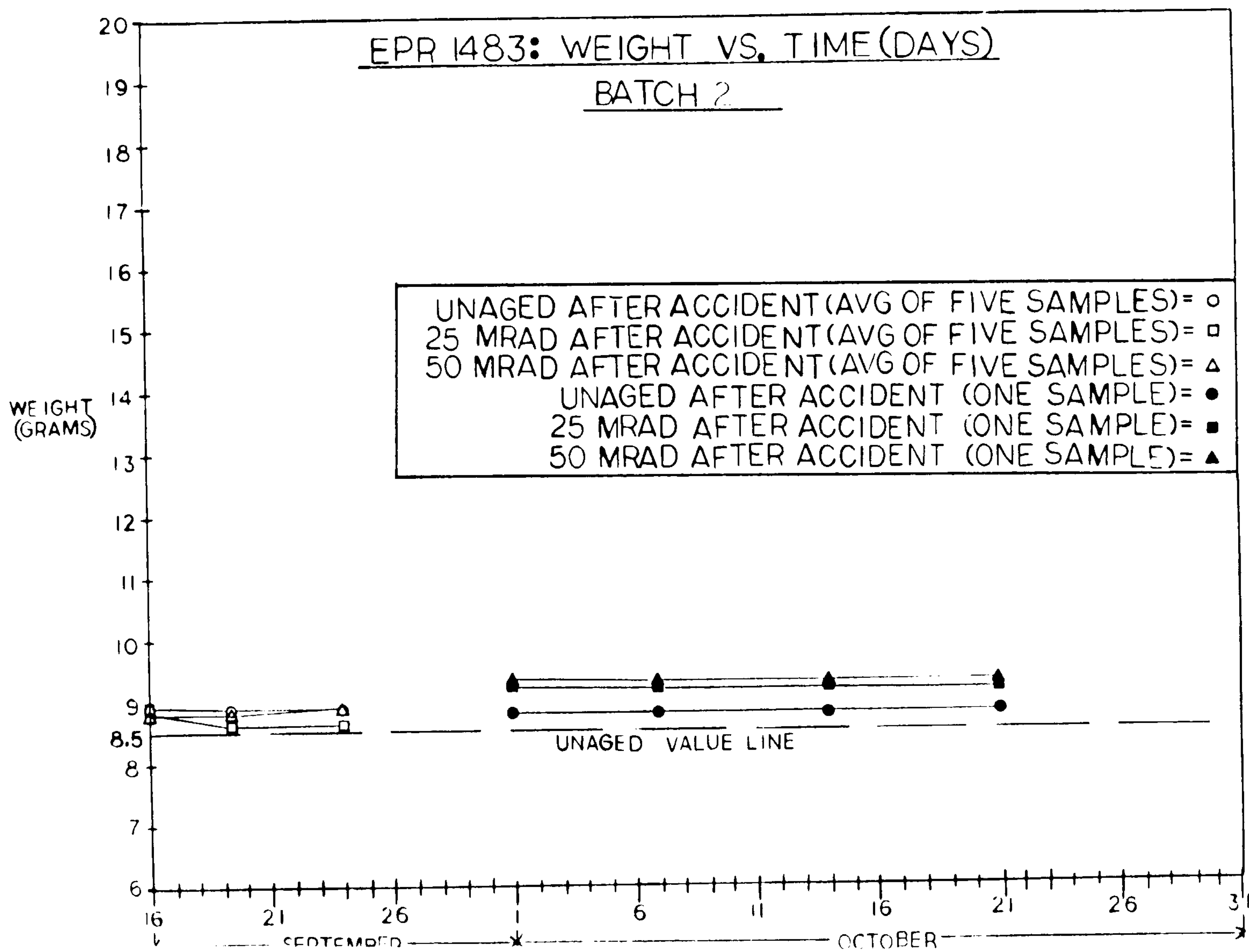
4
14
24
SEPT
OCT
NOV
DEC
JAN

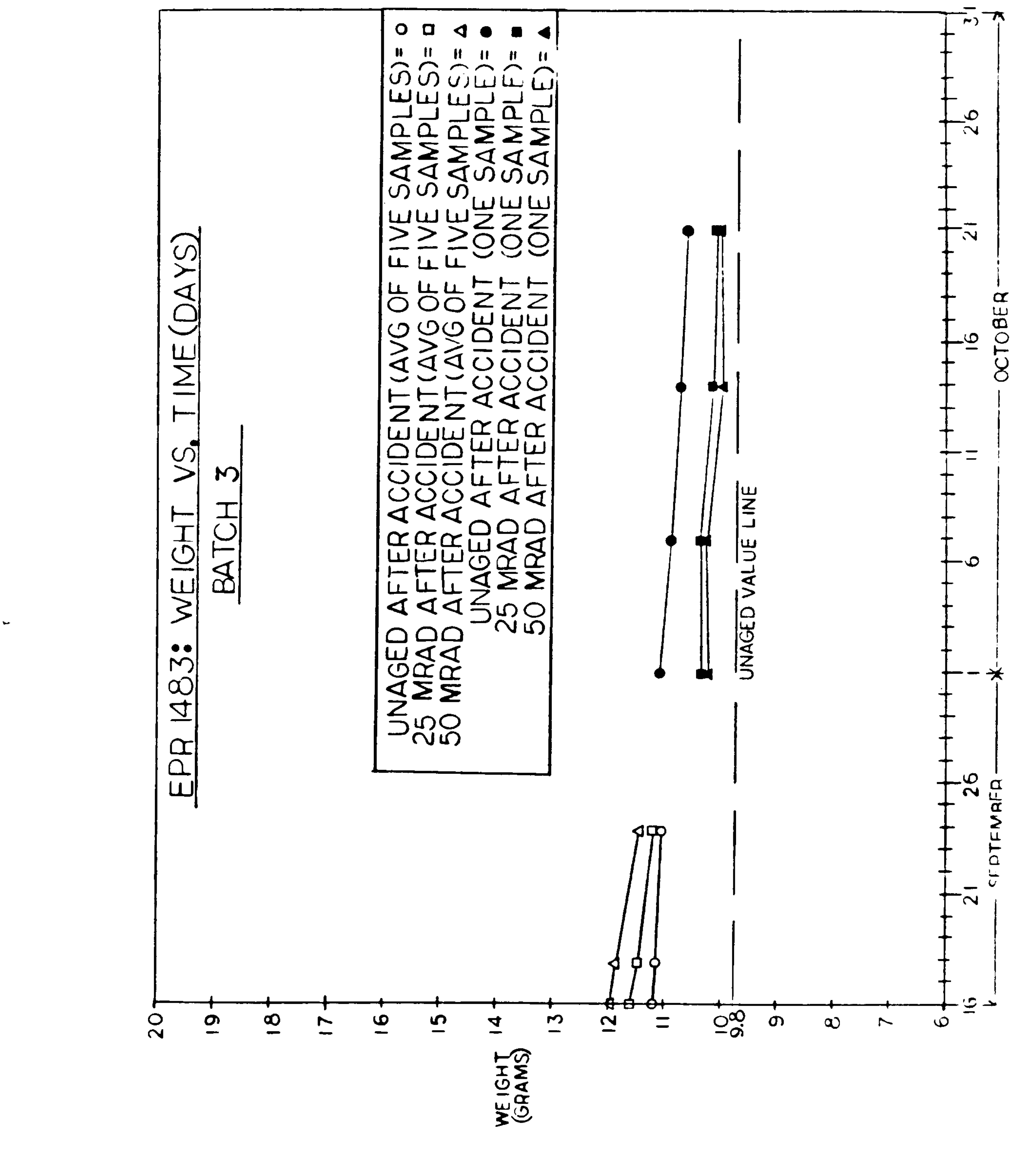

EPR F: WEIGHT VS. TIME
BATCH 5 AT 25 MRAD AND 50 MRAD
25 MRAD WT. = ●
50 MRAD WT. = ■
UNAGED WT. BEFORE TESTING = 10.0g
WEIGHT (GRAMS)
SEPT
OCT
NOV
DEC
JAN


EPRH : HIACA AND UNAGED WEIGHT VS. TIME
HIACA WT. = ●
UNAGED WT. = ■
UNAGED WT. BEFORE TESTING =6.8g
WEIGHT (GRAMS)
23 22 21 20 19 18 17 16 15 14 13 12 11 10 9 8 7 6
6.8
16 26 6 16 26 5 15 25 5 15 25 4 14 24
SEPT OCT NOV DEC JAN

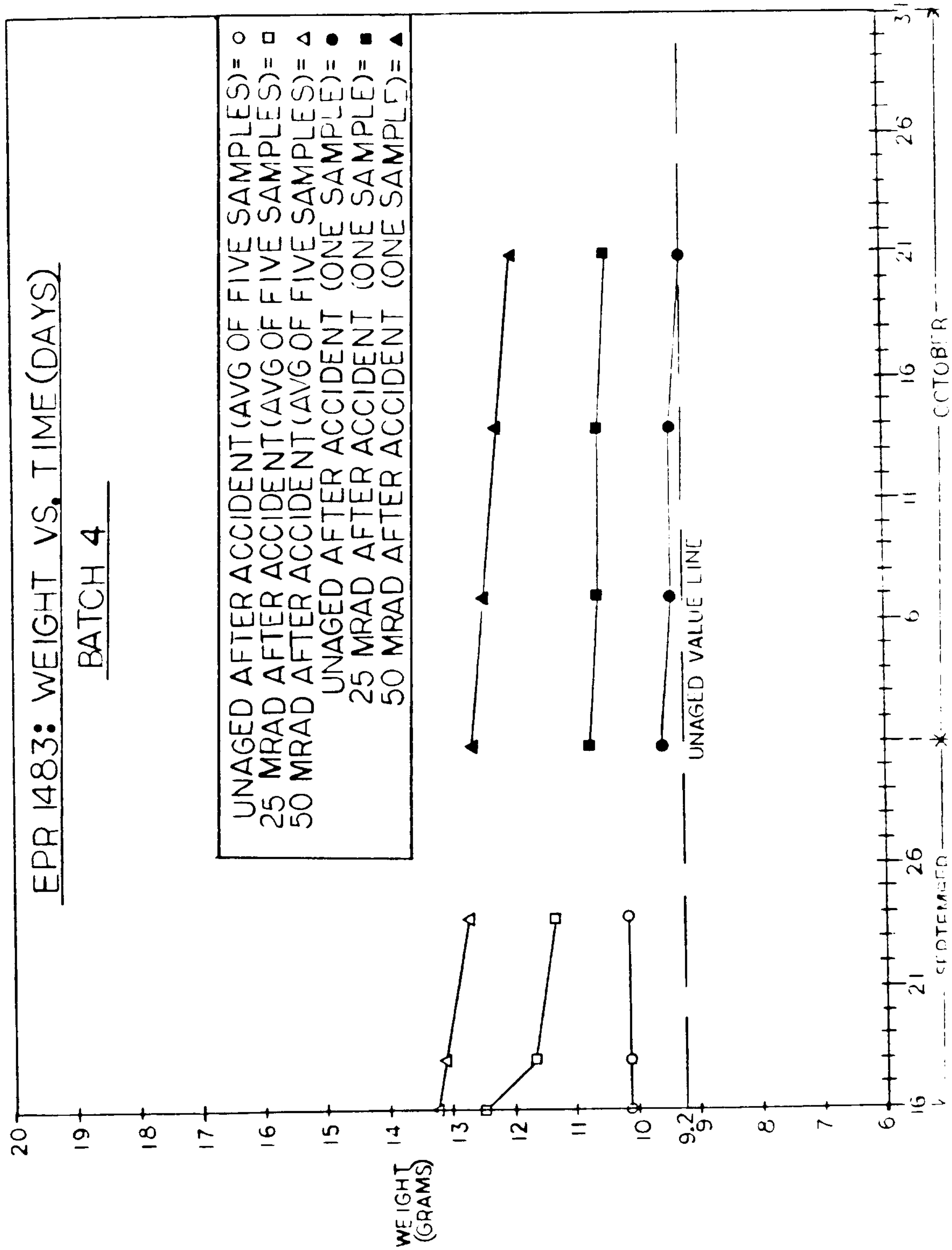


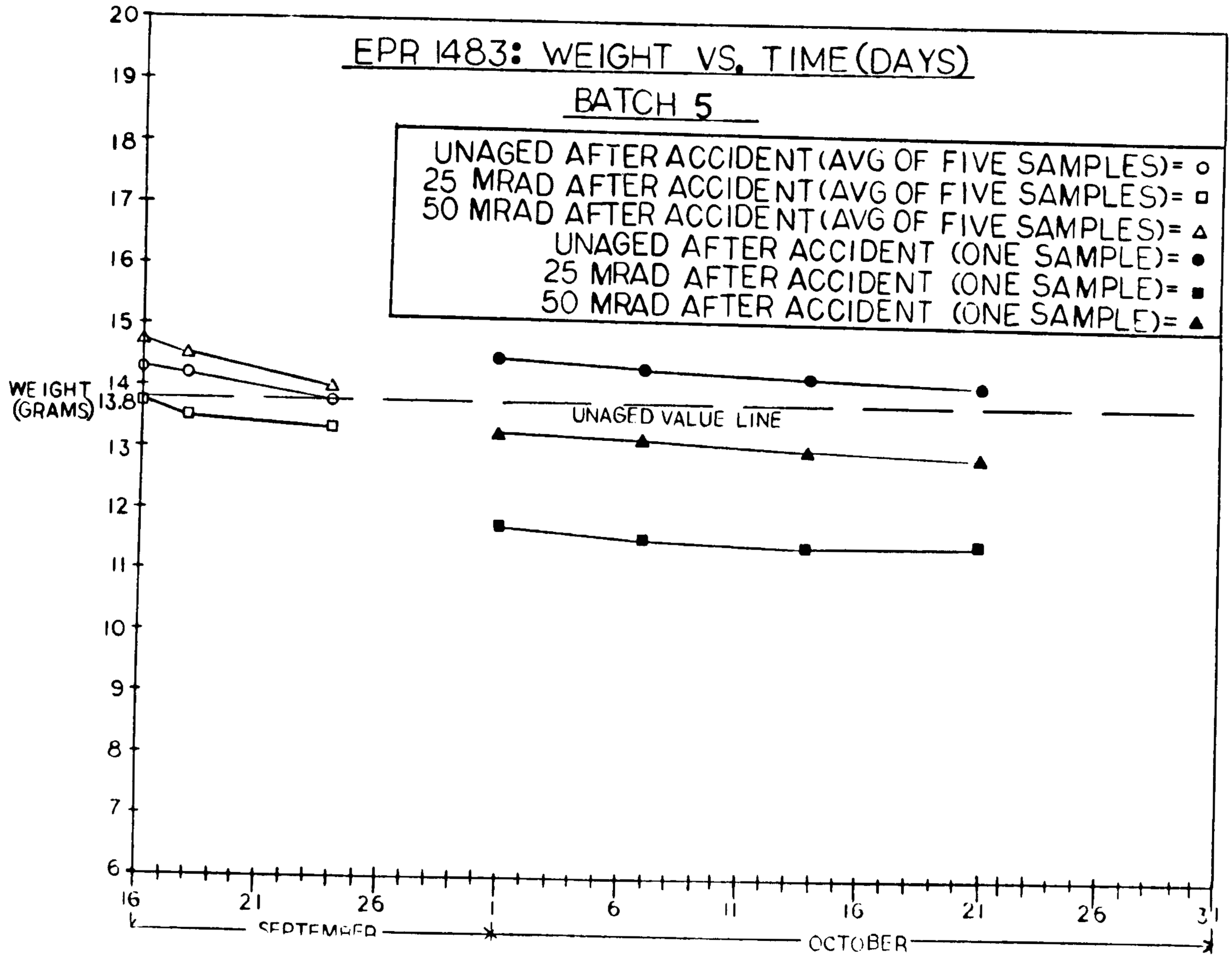
EPR 1483: WEIGHT VS. TIME (DAYS)
BATCH 1
UNAGED AFTER ACCIDENT (AVG OF FIVE SAMPLES) = ○
25 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = □
50 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = △
UNAGED AFTER ACCIDENT (ONE SAMPLE) = ●
25 MRAD AFTER ACCIDENT (ONE SAMPLE) = ■
50 MRAD AFTER ACCIDENT (ONE SAMPLE) = ▲
WEIGHT (GRAMS)
20
19
18
17
16
15
14
13
12
11
10
9.3
9
8
7
6
UNAGED VALUE LINE
16
21
26
1
6
11
16
21
26
31
SEPTEMBER
OCTOBER


EPR 1483: WEIGHT VS. TIME (DAYS)
BATCH 2
UNAGED AFTER ACCIDENT (AVG OF FIVE SAMPLES) = ○
25 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = □
50 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = △
UNAGED AFTER ACCIDENT (ONE SAMPLE) = ●
25 MRAD AFTER ACCIDENT (ONE SAMPLE) = ■
50 MRAD AFTER ACCIDENT (ONE SAMPLE) = ▲
WEIGHT (GRAMS)
20
19
18
17
16
15
14
13
12
11
10
9
8.5
8
7
6
UNAGED VALUE LINE
16
21
26
1
6
11
16
21
26
31
OCTOBER



EPR 1483: WEIGHT VS. TIME (DAYS)
BATCH 3
UNAGED AFTER ACCIDENT (AVG OF FIVE SAMPLES) = ○
25 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = □
50 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = △
UNAGED AFTER ACCIDENT (ONE SAMPLE) = ●
25 MRAD AFTER ACCIDENT (ONE SAMPLE) = ■
50 MRAD AFTER ACCIDENT (ONE SAMPLE) = ▲
UNAGED VALUE LINE
WEIGHT (GRAMS)
20
19
18
17
16
15
14
13
12
11
10
9.8
9
8
7
6
16
21
26
6
11
16
21
26
31
SEPTEMBER
OCTOBER


EPR 1483: WEIGHT VS. TIME (DAYS)
BATCH 4
UNAGED AFTER ACCIDENT (AVG OF FIVE SAMPLES) = ○
25 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = □
50 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = △
UNAGED AFTER ACCIDENT (ONE SAMPLE) = ●
25 MRAD AFTER ACCIDENT (ONE SAMPLE) = ■
50 MRAD AFTER ACCIDENT (ONE SAMPLE) = ▲
UNAGED VALUE LINE
WEIGHT (GRAMS)
20
19
18
17
16
15
14
13
12
11
10
9.2
9
8
7
6
16
21
26
6
11
16
21
26
31
SEPTEMBER
OCTOBER


EPR 1483: WEIGHT VS. TIME (DAYS)
BATCH 5
UNAGED AFTER ACCIDENT (AVG OF FIVE SAMPLES) = ○
25 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = □
50 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = △
UNAGED AFTER ACCIDENT (ONE SAMPLE) = ●
25 MRAD AFTER ACCIDENT (ONE SAMPLE) = ■
50 MRAD AFTER ACCIDENT (ONE SAMPLE) = ▲
UNAGED VALUE LINE
WEIGHT (GRAMS)
20
19
18
17
16
15
14
13.8
13
12
11
10
9
8
7
6
16
21
26
1
6
11
16
21
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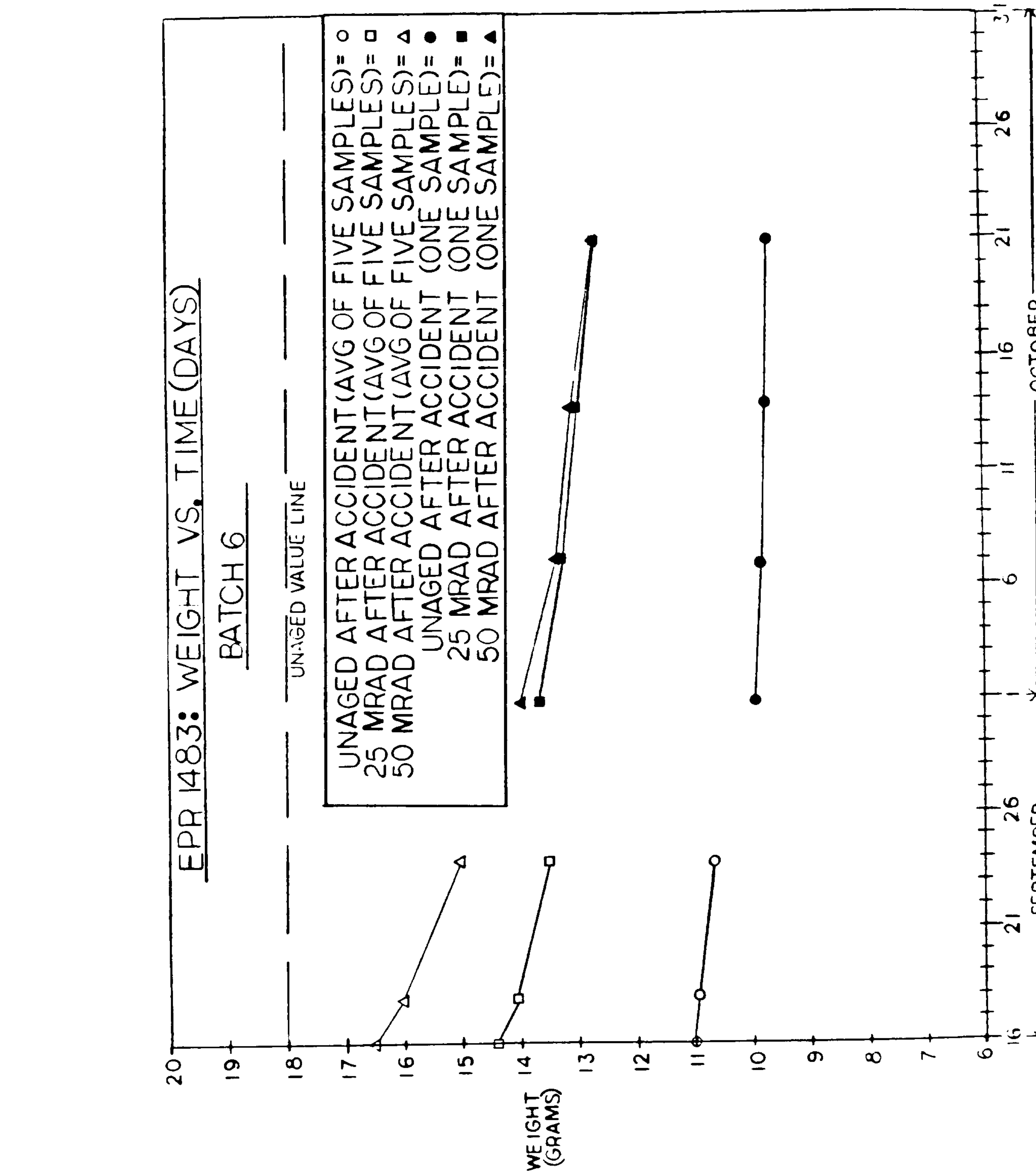
31
SEPTEMBER
OCTOBER


EPR 1483: WEIGHT VS. TIME (DAYS)
BATCH 6
UNAGED VALUE LINE
UNAGED AFTER ACCIDENT (AVG OF FIVE SAMPLES) = ○
25 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = □
50 MRAD AFTER ACCIDENT (AVG OF FIVE SAMPLES) = △
UNAGED AFTER ACCIDENT (ONE SAMPLE) = ●
25 MRAD AFTER ACCIDENT (ONE SAMPLE) = ■
50 MRAD AFTER ACCIDENT (ONE SAMPLE) = ▲
WEIGHT (GRAMS)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
16
21
26
1
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11
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21
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MONTH: June YEAR: 1986

5 AUTHOR(S)
P. R. Bennett, S. D. St.Clair (K tech), and T. W. Gilmore (G_2VanTel)

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b PERIOD COVERED (Inclusive dates)

12 SUPPLEMENTARY NOTES

13 ABSTRACT (200 words or less)

The superheated-steam test exposed different ethylene propylene rubber (EPR) cables and insulation specimens to simultaneous aging and a 21-day simultaneous accident environment. In addition, some insulation specimens were exposed to five different aging conditions prior to the 21-day simultaneous accident simulation. The purpose of this superheated-steam test (a follow-on to the saturated-steam tests (NUREG/CR-3538) was to (1) examine electrical degradation of different configurations of EPR cables,(2) investigate differences between using superheated-steam or saturated-steam at the start of an accident simulation, (3) determine whether the aging technique used in the saturated-steam test induced artificial degradation, and (4) identify the constituents in EPR which affect moisture absorption.

The cable electrical degradation was determined by insulation resistance and AC leakage current measurements. One aged multiconductor cable product had electrical degradation, although the aged single conductor cable did not have electrical degradation. Therefore, the current qualification practice of using single conductor cables to qualify multiconductor cables may not be a conservative approach for all cables. Physical and tensile properties (measured after the accident) for insulation specimens did not improve as the accelerated aging time was increased. Therefore, the aging technique did not induce artificial degradation. In addition, the constituents that appear to affect moisture absorption and/or produce other chemical changes are fire retardants, nonsurface treated clay, or lack of vinyl silane.

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